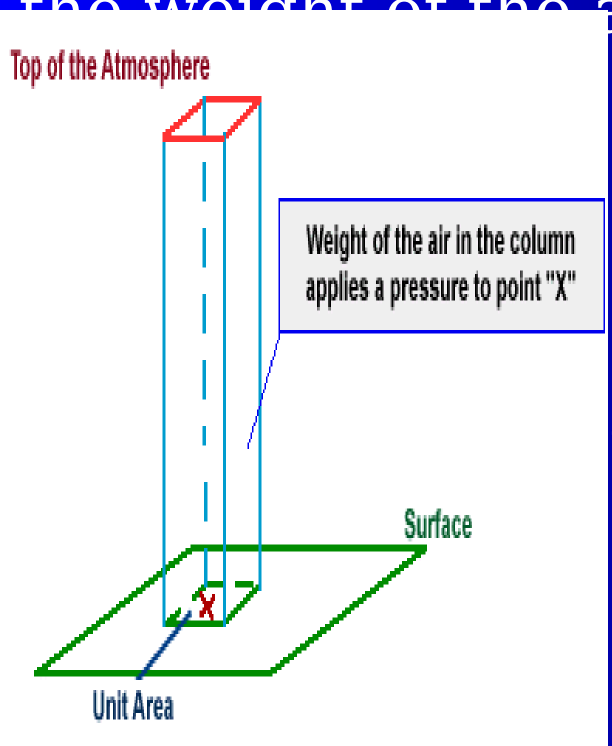
Forces and Winds

Atmospheric Pressure

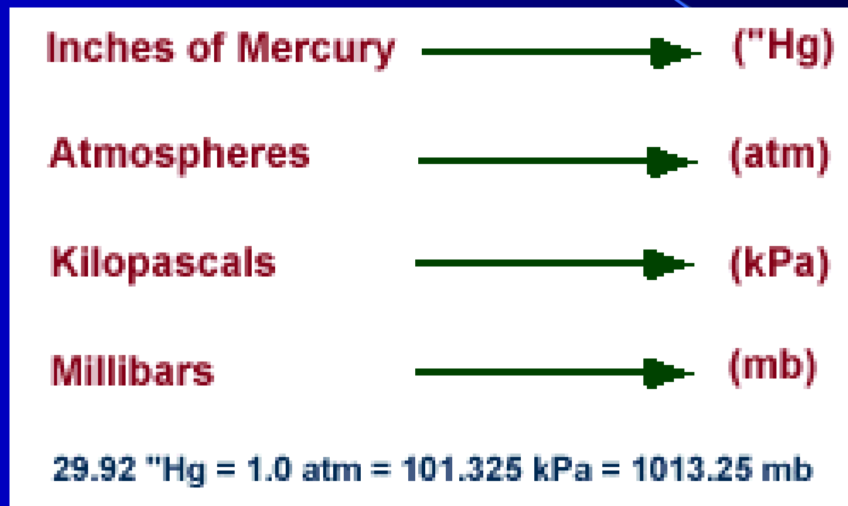
force exerted by the weight of the air

Atmospheric pressure is defined as the force per unit area exerted against a surface by the weight of the air above that surface. In the diagram below, the pressure at point "X" increases as the weight of the air above it increases. The same can be said about decreasing pressure, where the pressure at point "X" decreases if the weight of the air above it also decreases.



Thinking in terms of air molecules, if the number of air molecules above a surface increases, there are more molecules to exert a force on that surface and consequently, the pressure increases. The opposite is also true, where a reduction in the number of air molecules above a surface will result in a decrease in pressure. Atmospheric pressure is measured with an instrument called a "barometer", which

In aviation and television weather reports, pressure is given in inches of mercury ("Hg), while meteorologists use millibars (mb), the unit of pressure found on weather maps.

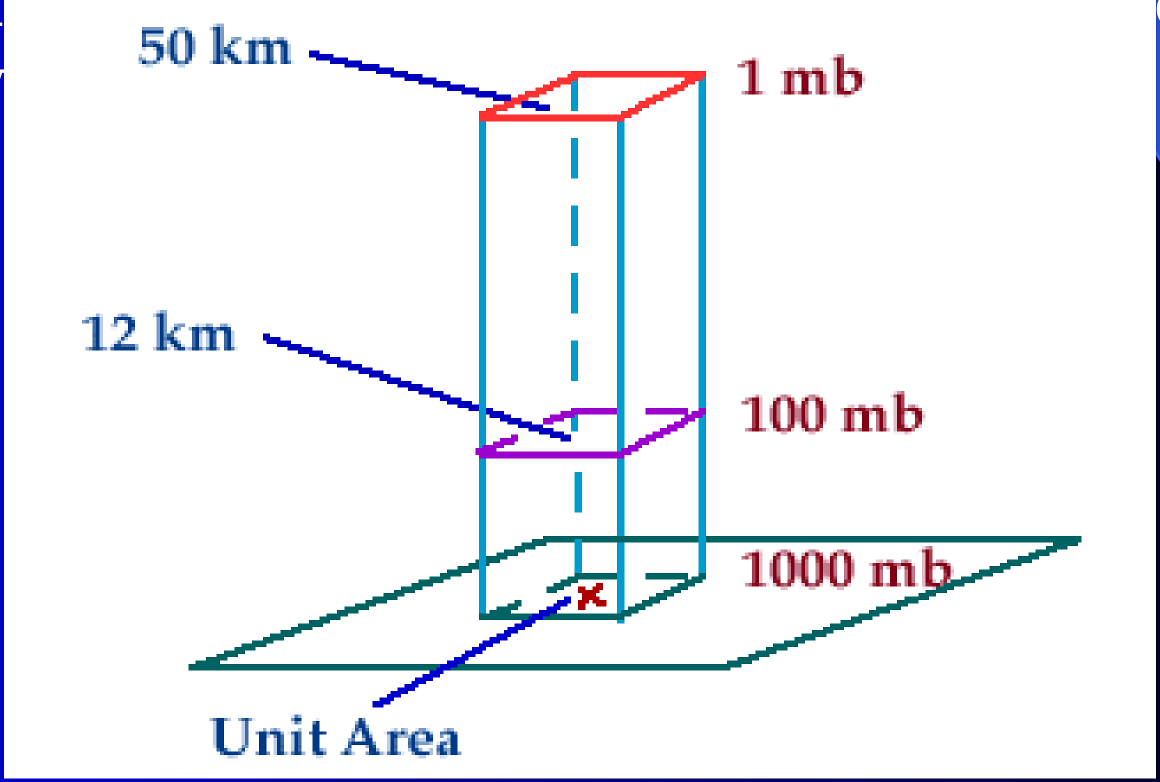


As an example, consider a "unit area" of 1 square inch. At sea level, the weight of the air above this unit area would (on average) weigh 14.7 pounds! That means pressure applied by this air on the unit area would be 14.7 pounds per square inch. Meteorologists use a metric unit for pressure called a millibar and the average pressure at

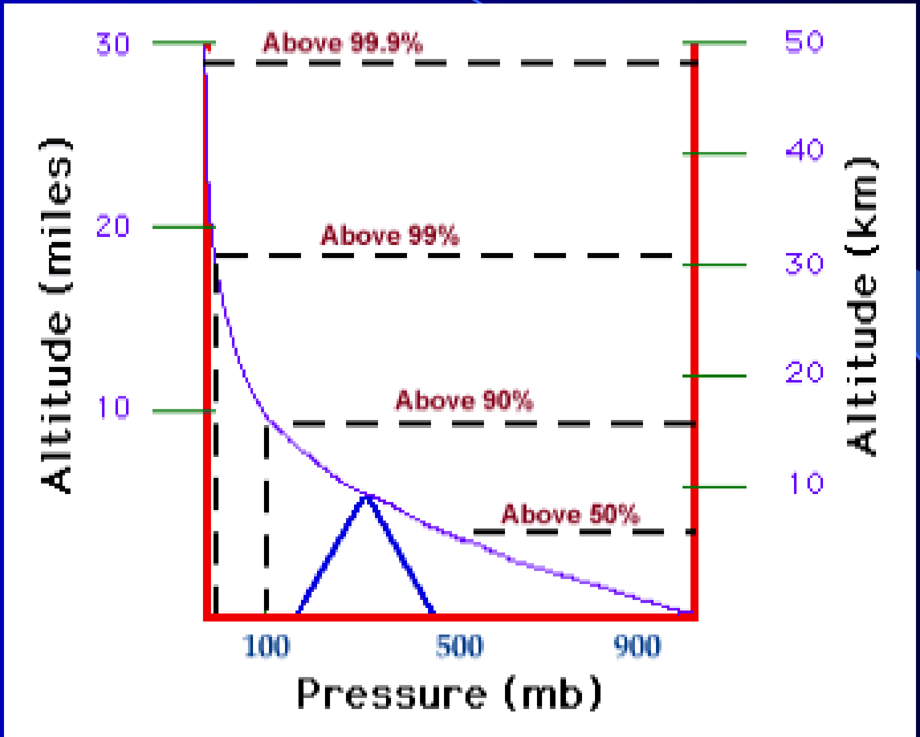
Pressure with Height

pressure decreases with increasing altitude

The number of air molecules above a surface changes as the height of the surface above the ground changes. For example, there are fewer air molecules above the 50 kilometer (km) surface than are found above the 12 km surface. Since the number of air molecules above a surface decreases with height, pressure likewise decreases w



Most of the atmosphere's molecules are held close to the earth's surface by gravity. Because of this, air pressure decreases rapidly at first, then more slowly at higher levels.

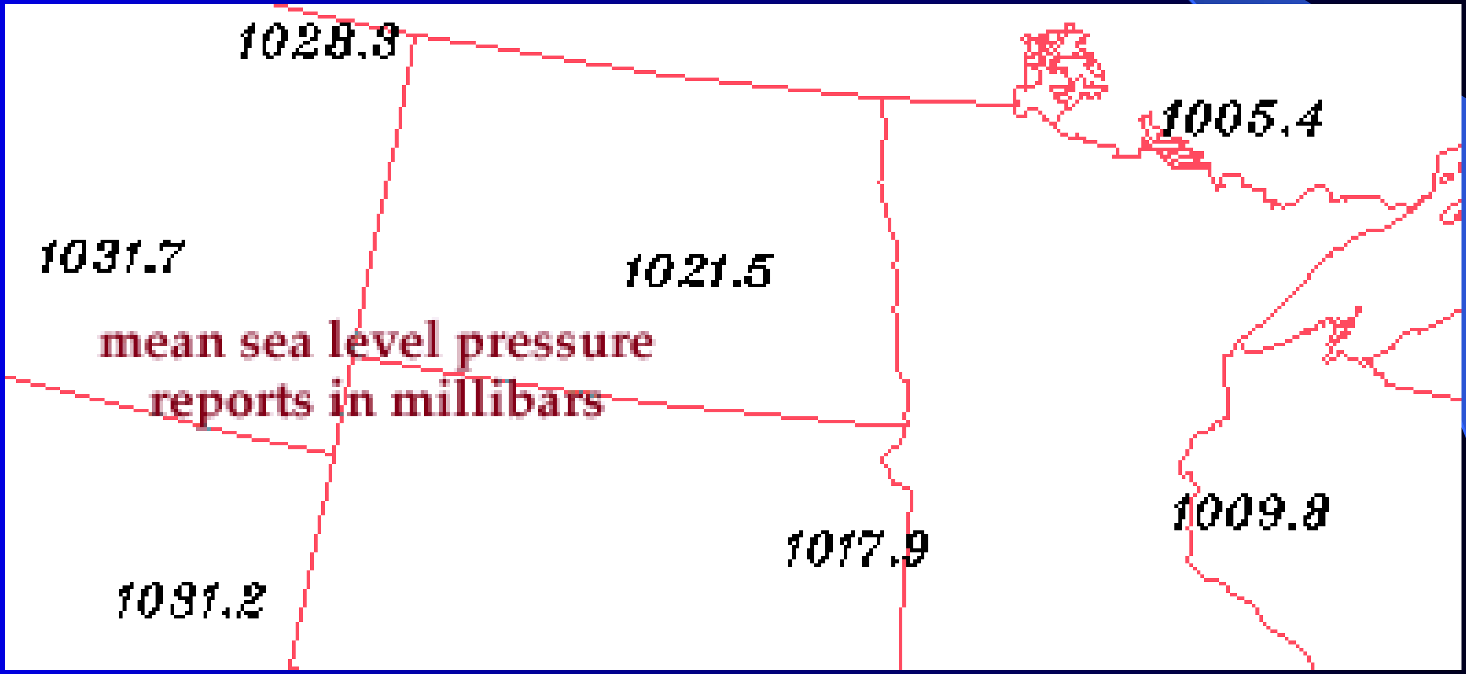


Since more than half of the atmosphere's molecules are located below an altitude of 5.5 km, atmospheric pressure decreases roughly 50% (to around 500 mb) within the lowest 5.5 km. Above 5.5 km, the pressure continues to decrease, but at an increasingly slower rate (to about 1 mb at 48 km).

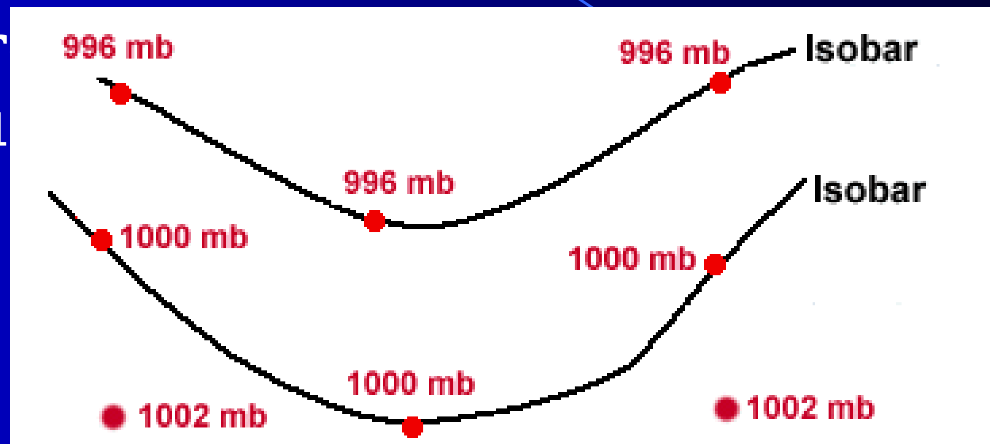
Isobars

lines of constant pressure

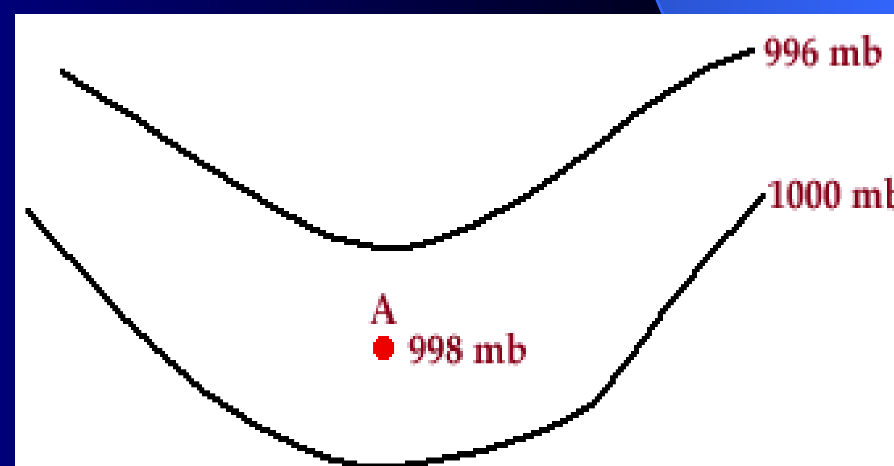
A line drawn on a weather map connecting points of equal pressure is called an "isobar". Isobars are generated from mean sea-level pressure reports and are given in millibars.



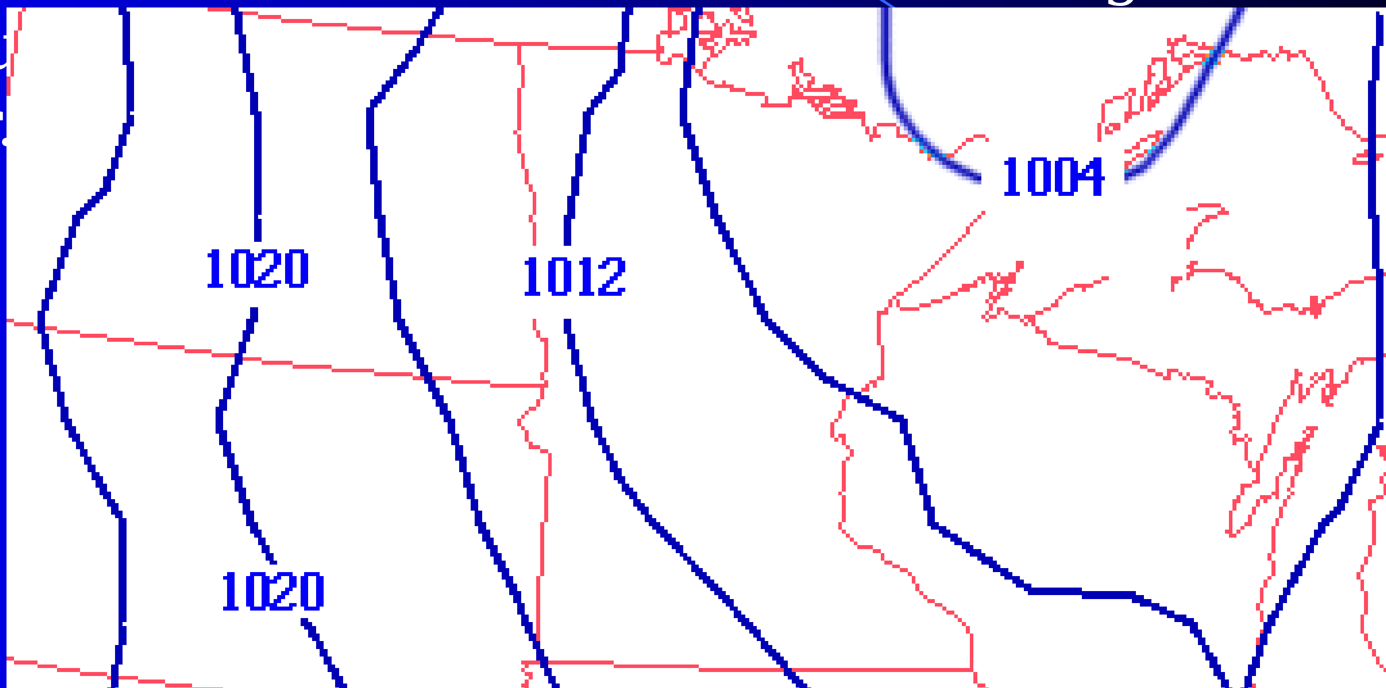
The diagram below depicts a pair of sample isobars. At every point along the top isobar, the pressure is 996 mb while at every point along the bottom isobar, the pressure is 1000 mb. Points above the 1000 mb isobar have a lower pr sobar have a higher pressu



Any point lying in between these two isobars must have a pressure somewhere between 996 mb and 1000 mb. Point A, for example, has a pressure of 998 mb and is therefore located between the 996 mb



Sea-level pressure reports are available every hour, which means that isobar maps are likewise available every hour. The solid blue contours (in the map below) represent isobars and the numbers along selected contou cular isobar.

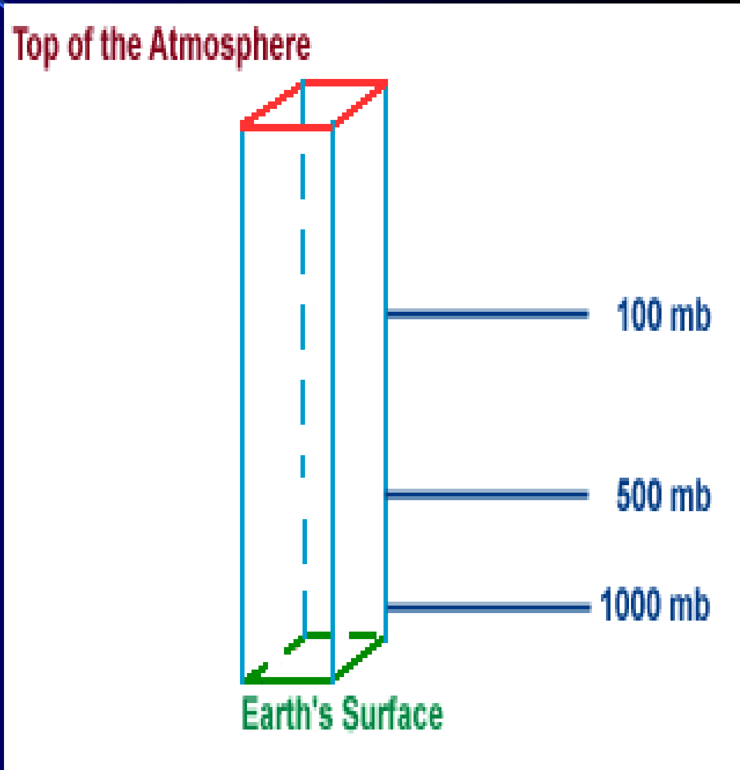


Such maps are useful for locating areas of high and low pressure, which correspond to the positions of surface cyclones and anticyclones. A map of isobars is also useful for locating strong pressure gradients, which are identifiable by a tight packing of the isobars. Stronger

Constant Pressure Surfaces

a surface of equal pressure, also called an isobaric surface

A constant pressure (or isobaric) surface is a surface in the atmosphere where the pressure is equal everywhere along that surface. For example, the 100 millibar (mb) surface is the surface in the atmosphere where the pressure at every point along that surface is 100 mb. Since pressure decreases with height, the altitude of the 100 mb surface is higher than the 500 mb surface, which is likewise higher than 1000 mb. Meteorologists use pressure as a vertical coordinate



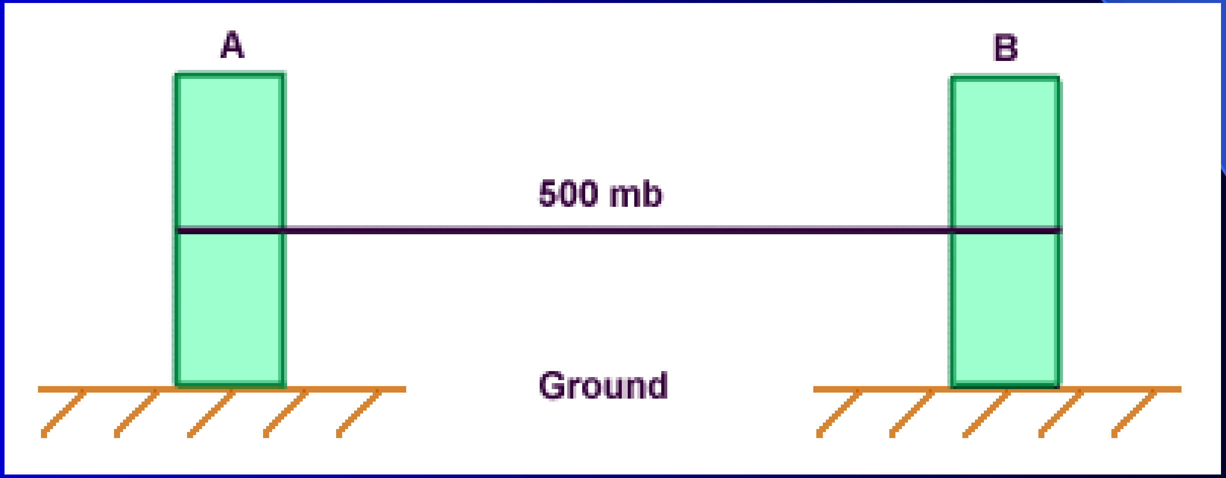
Measurements of the upper atmosphere (temperature, pressure, winds, etc.) are taken by instruments on weather balloons as they rise upward from the earth. When referring to the 500 mb surface, we mean a location in the atmosphere where the pressure has been measured to be 500 mb. The approximate heights and temperatures for several constant pressure surfaces have been listed below:

Pressure	Approximate Height		Approximate Temperature	
Sea Level	0 m	0 ft	15 C	59 F
1000mb	100 m	300 ft	15 C	59 F
850 mb	1500 m	5000 ft	05 C	41 F
700 mb	3000 m	10000 ft	-05 C	23 F
500 mb	5000 m	18000 ft	-20 C	-04 F
300 mb	9000 m	30000 ft	-45 C	-49 F
200 mb	12000 m	40000 ft	-55 C	-67 F
100 mb	16000 m		-56 C	-69F

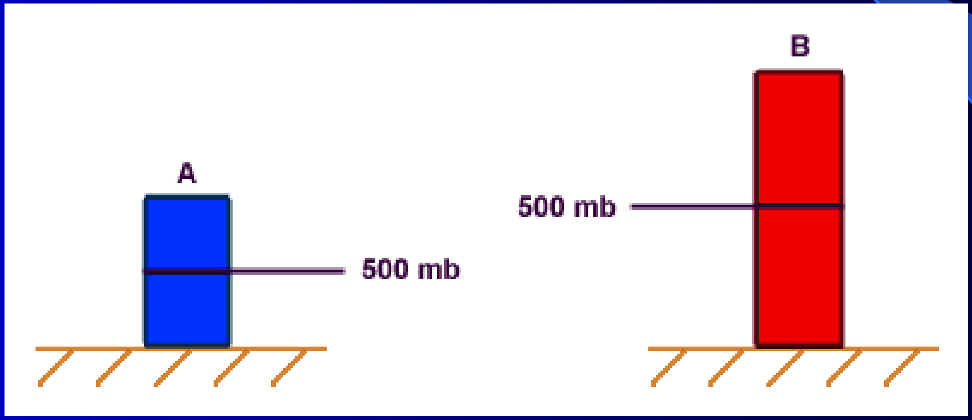
The atmospheric variables typically plotted on isobaric maps include: height of the pressure surface, temperature, moisture content and wind speed and

the relationship between pressure surfaces and temperature

The height of a given pressure surface above the ground varies with temperature. As an example, consider two identical columns of air (A and B). Since they are identical, the 500 mb surface is found at the same height in each column.



Cooling column A and heating column B changes the height of the 500 mb surface in each column. Since colder air contracts, the height of the 500 mb surface in column A decreases, while in column B, the warm air expands, raising the height of the 500 mb surface.

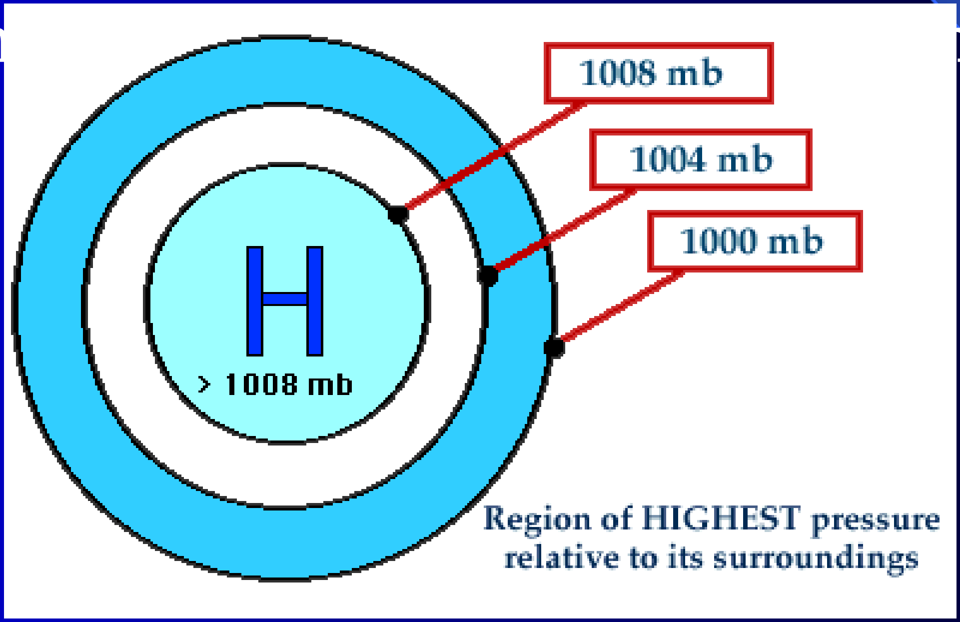


Therefore, where the temperatures are colder, a given pressure surface will have a lower height than if the same pressure surface was located in warmer air.

High Pressure Centers

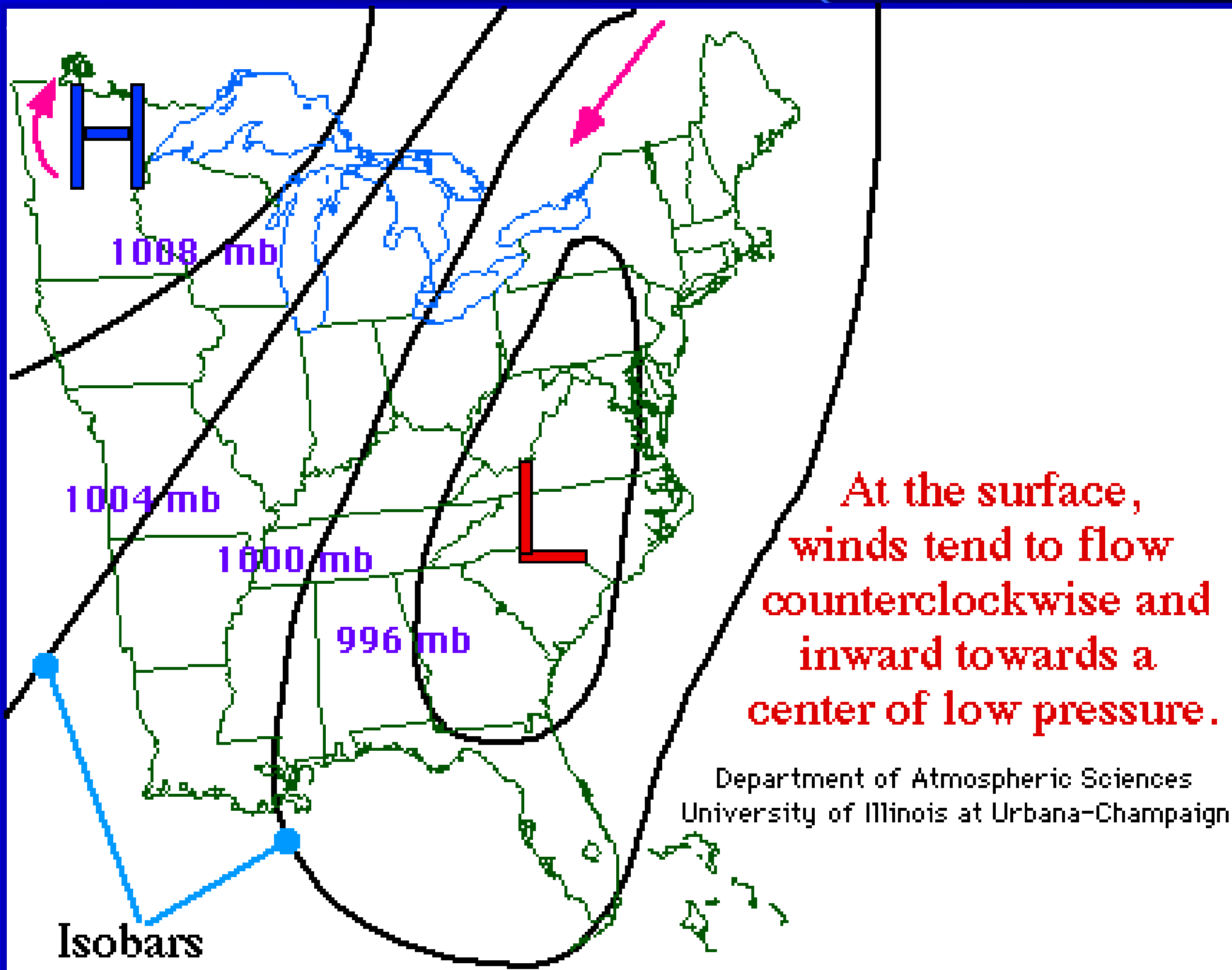
also known as anticyclones

A high pressure center is where the pressure has been measured to be the highest relative to its surroundings. That means, moving in any direction away from the "High" will result in a decrease in pressure. A high pressure center also represents the center of an anticyclone an … nap by a blue "H".



Winds flow clockwise around a high pressure center in the northern hemisphere, while in the southern hemisphere, winds flow counterclockwise around a high.

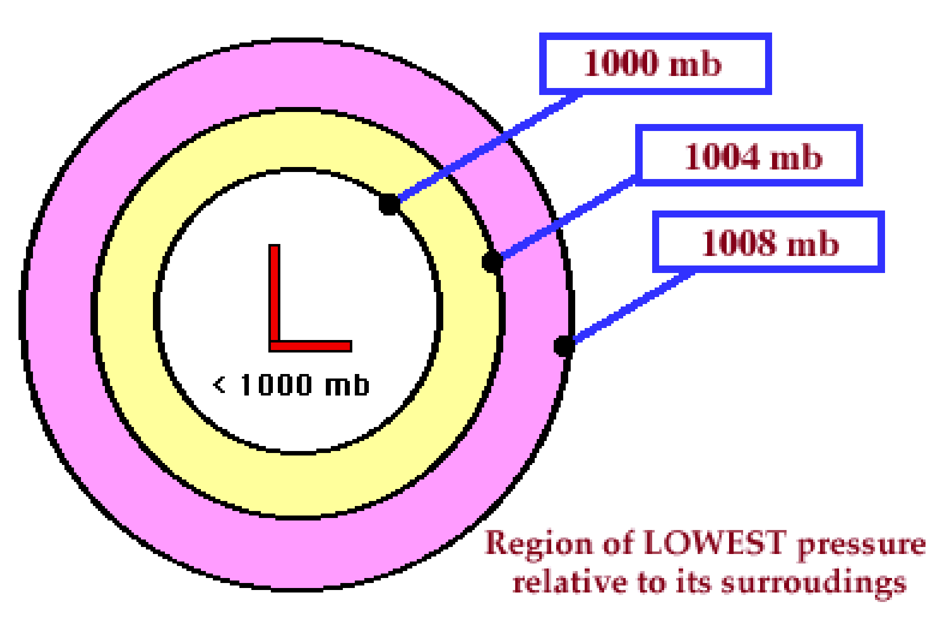
Sinking air in the vicinity of a high pressure center suppresses the upward motions needed to support the development of clouds and precipitation. This is why fair weather is commonly associated with an area of high pressure.



Low Pressure Centers

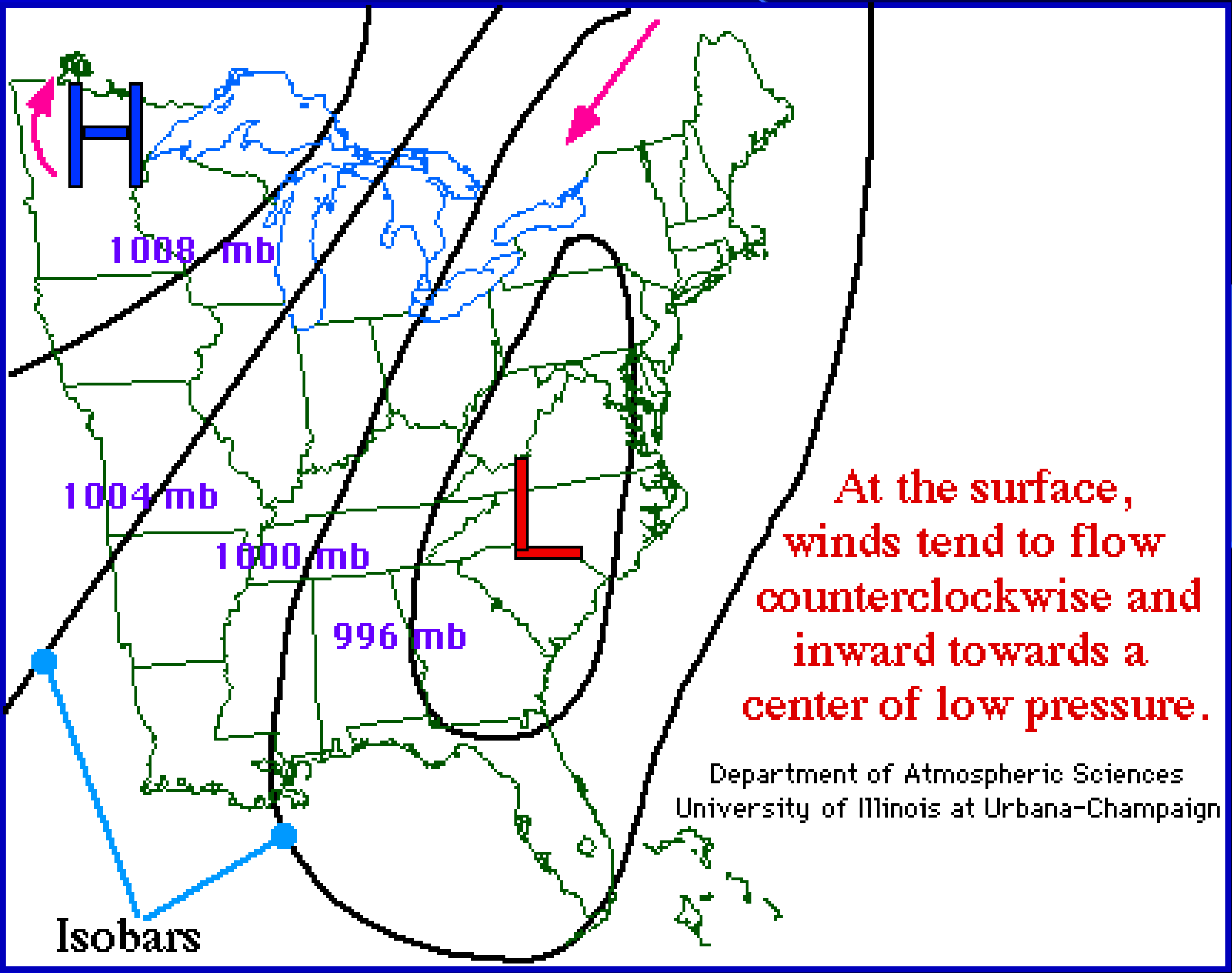
also known as cyclones

A low pressure center is where the pressure has been measured to be the lowest relative to its surroundings. That means, moving in any horizontal direction away from the "Low" will result in an increase in pressure. Low pressure centers also represent the centers of cyclones.



A low pressure center is indicated on a weather map by a red "L" and winds flow counterclockwise around a low in the northern hemisphere. The opposite is true in the southern hemisphere, where winds flow clockwise

Rising motion in the vicinity of a low pressure center favors the development of clouds and precipitation, which is why cloudy weather (and likely precipitation) are commonly associated with an area of low pressure.



REVIEW

Atmospheric pressure is defined as:

the force per unit area exerted against a surface by the weight of the air above that sfc

29.92 Inches of Mercury = ____ millibars. 1013.25

Pressure ______ with an increase in height. decreases

Isobars are ___________________________. Lines of constant pressure.

True or False. A constant pressure surface is a surface in the atmosphere where the pressure is equal everywhere along that surface. True

500 Mb = ________ ft. 18,000

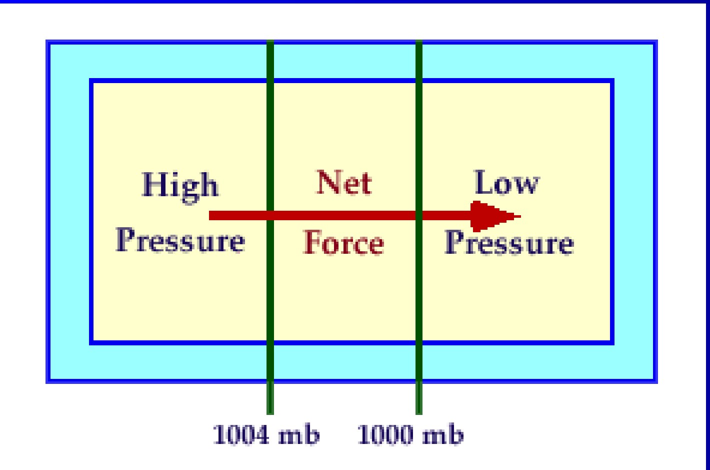
Where the temperatures are _______, a given pressure surface will have a ______ height than if the same pressure surface was located in warmer air. Colder, lower

High pressure centers are known as _____, while low pressure centers are known as _______. Anticyclones, cyclones

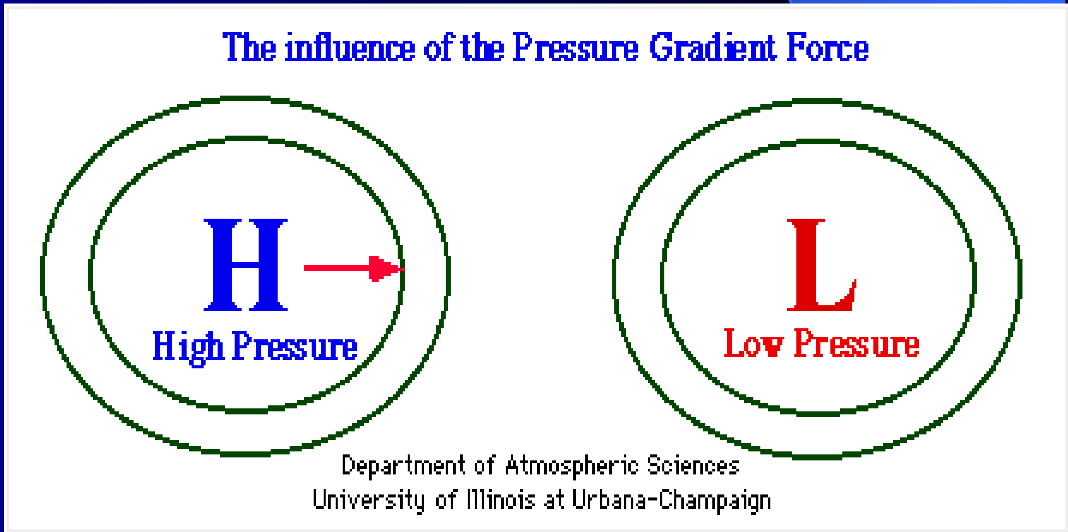
Pressure Gradient Force

directed from high to low pressure

The change in pressure measured across a given distance is called a "pressure gradient".



The pressure gradient results in a net force that is directed from high to low pressure and this force is called the "pressure gradient force".

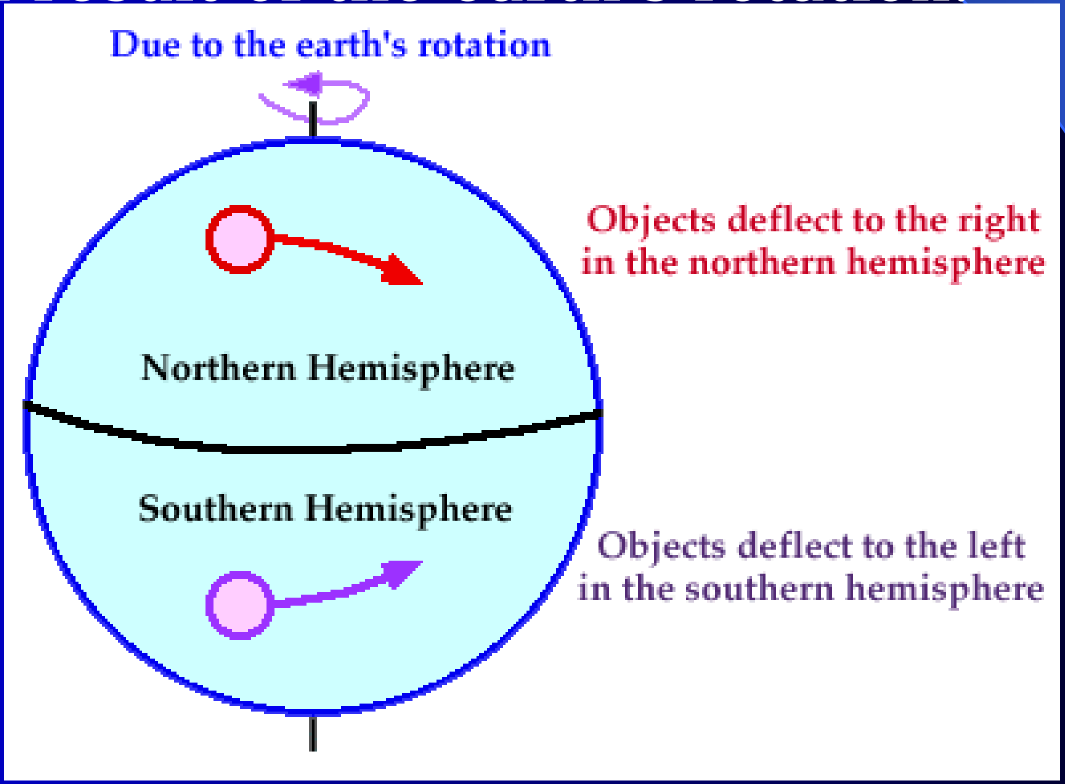


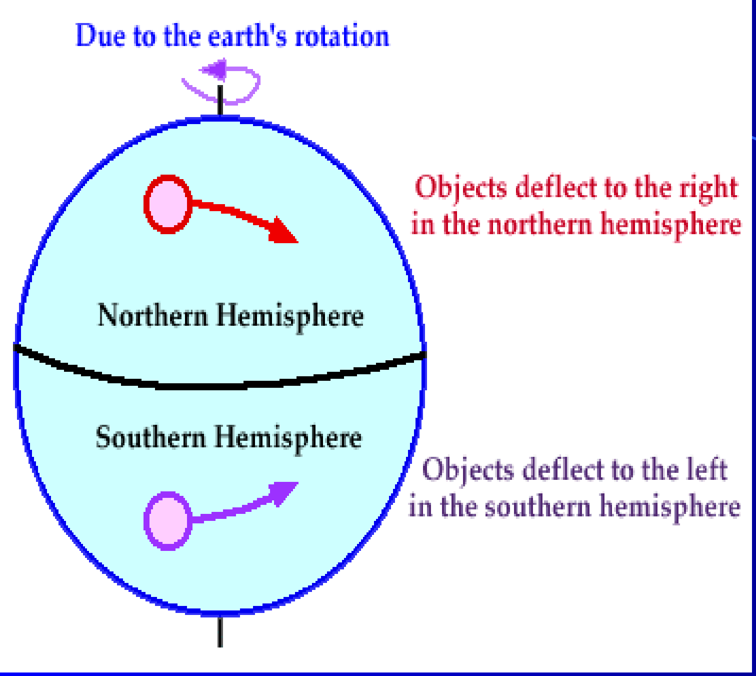
The pressure gradient force is responsible for triggering the initial movement of air.

Coriolis Force

an artifact of the earth's rotation

Once air has been set in motion by the pressure gradient force, it undergoes an apparent deflection from its path, as seen by an observer on the earth. This apparent deflection is called the "Coriolis force" and is a result of the earth's rotation.





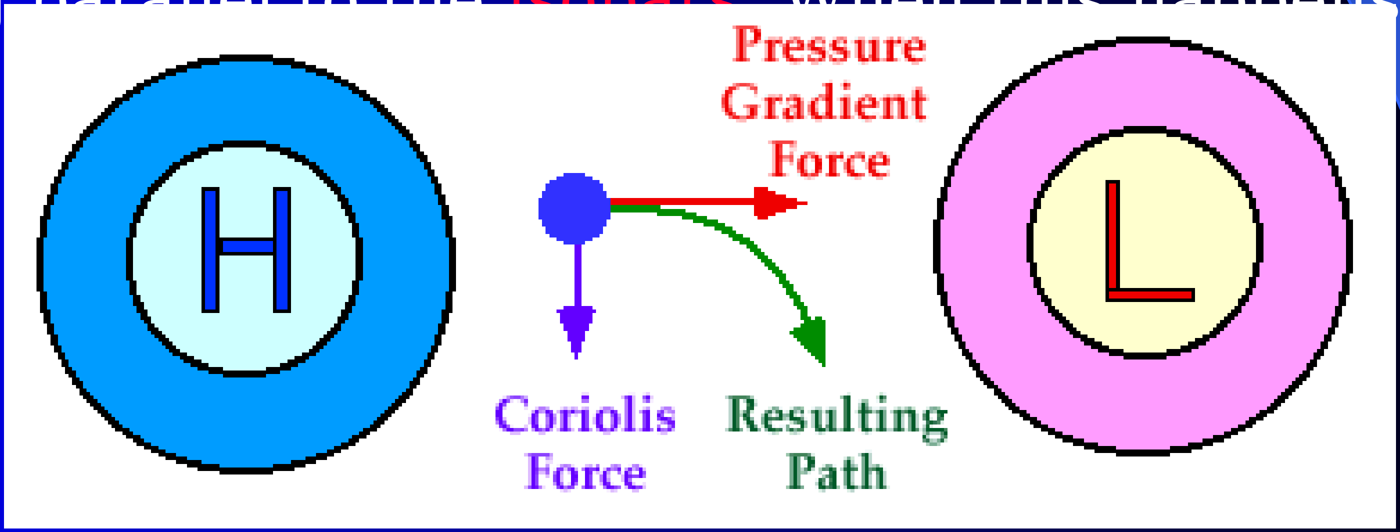
As air moves from high to low pressure in the northern hemisphere, it is deflected to the right by the Coriolis force. In the southern hemisphere, air moving from high to low pressure is deflected to the left by the Coriolis force.

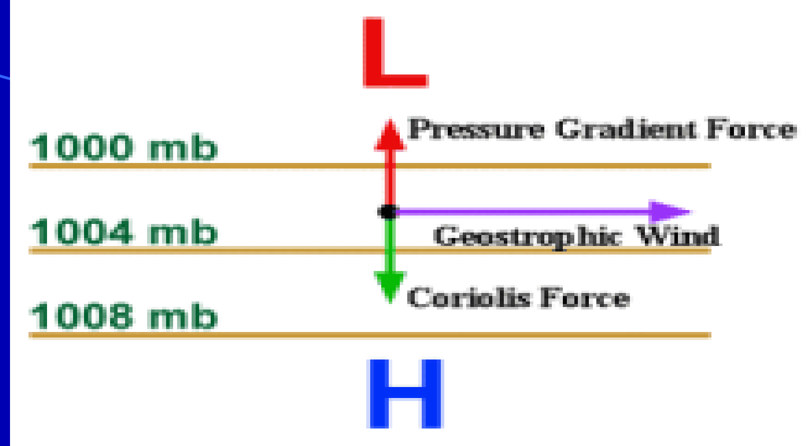
The amount of deflection the air makes is directly related to both the speed at which the air is moving and its latitude. Therefore, slowly blowing winds will be deflected only a small amount, while stronger winds will be deflected more. Likewise, winds blowing closer to the poles will be deflected more than winds at the same speed closer to the equator. The Coriolis force is zero right at the equator.

Geostrophic Wind

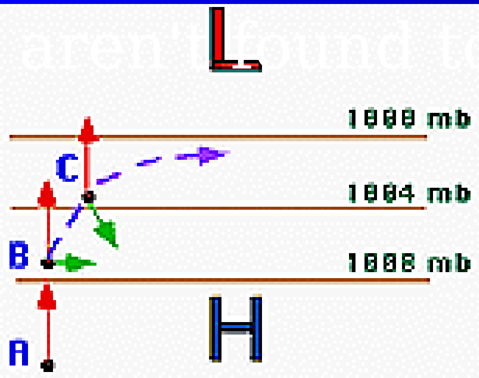
winds balanced by the Coriolis and Pressure Gradient forces

An air parcel initially at rest will move from high pressure to low pressure because of the pressure gradient force (PGF). However, as that air parcel begins to move, it is deflected by the Coriolis force to the right in the northern hemisphere (to the left on the southern hemisphere). As the wind gains speed, the deflection increases until the Coriolis force equals the pressure gradient force. At this point, the wind will be blowing parallel to the isobars. When this happens, the wind is





The movie below illustrates the process mentioned above, while the diagram at right shows the two forces balancing to produce the geostrophic wind. Winds in nature are rarely exactly geostrophic, but to a good approximation, the winds in the upper troposphere can be close. This is because winds are only considered truly geostrophic when the isobars are straight and there are no other forces acting on it -- and these conditions just aren't found too often in nature.

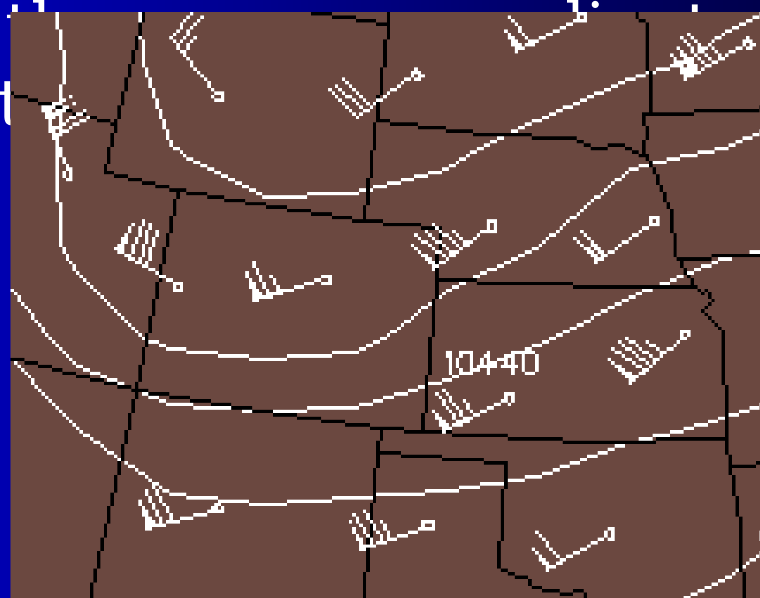


This animation depicts how the pressure gradient and Coriolis forces influence the movement of air parcels.

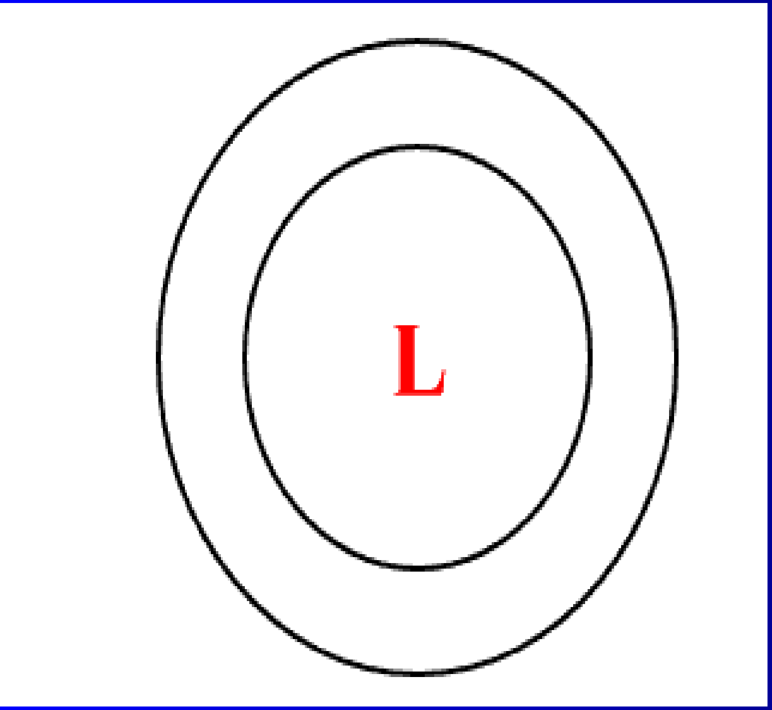
Gradient Wind

non-geostrophic winds which blow parallel to isobars

Geostrophic winds exist in locations where there are no frictional forces and the isobars are straight. However, such locations are quite rare. Isobars are almost always curved and are very rarely evenly spaced. This changes the geostrophic winds so that they are no longer geostrophic but are instead in **gradient wind balance**. They still blow parallel to the isobars, but are no longer balanced by only th nd Coriolis forces, and do not y as geostrophic winds.

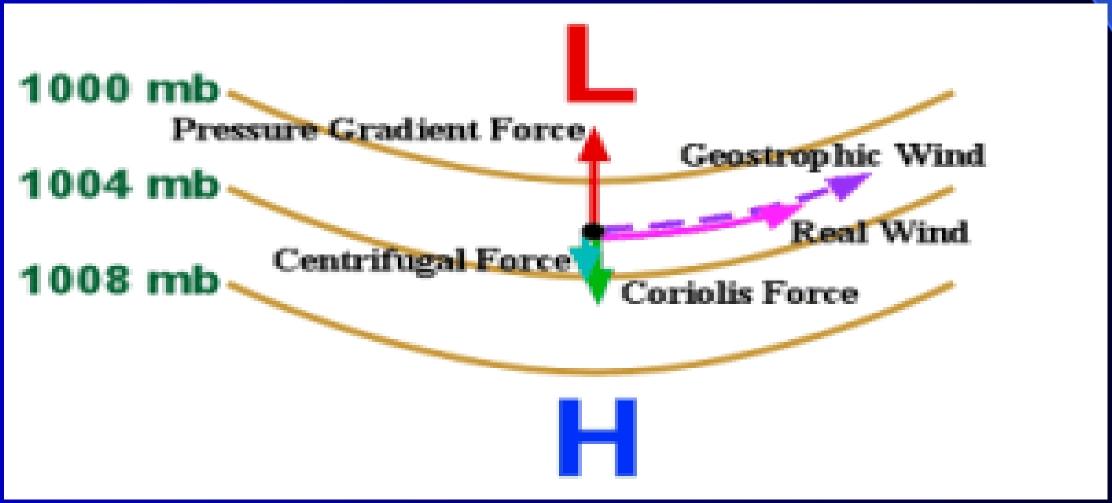


In the diagram below at point A, the parcel of air will move straight north. The pressure gradient and Coriolis forces are present, but when the isobars are curved, there is a third force -- the centrifugal force. This apparent force, pushes objects away from the center of a circle. The centrifugal force alters the original two-force balance and creates the non-geostrophic gradient wind.

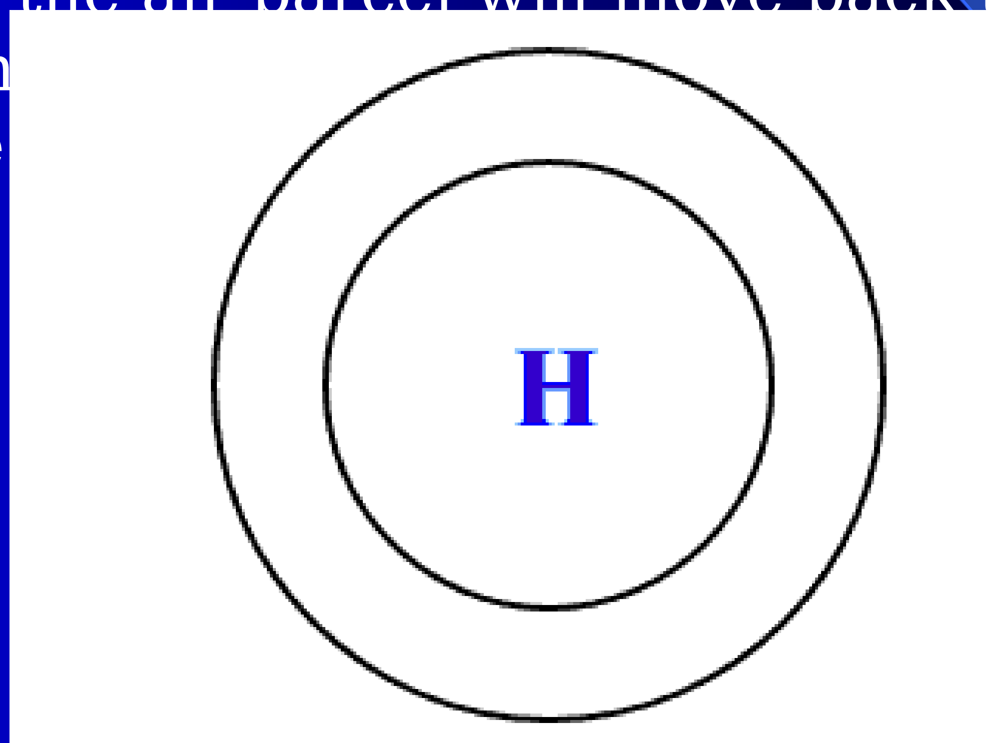


In this case, the centrifugal force acts in the same direction as the Coriolis force. As the parcel moves north, it moves slightly away from the center -- decreases the centrifugal force. The pressure gradient force becomes slightly more dominant and the parcel moves back to the original radius. This allows the gradient wind to blow parallel to the

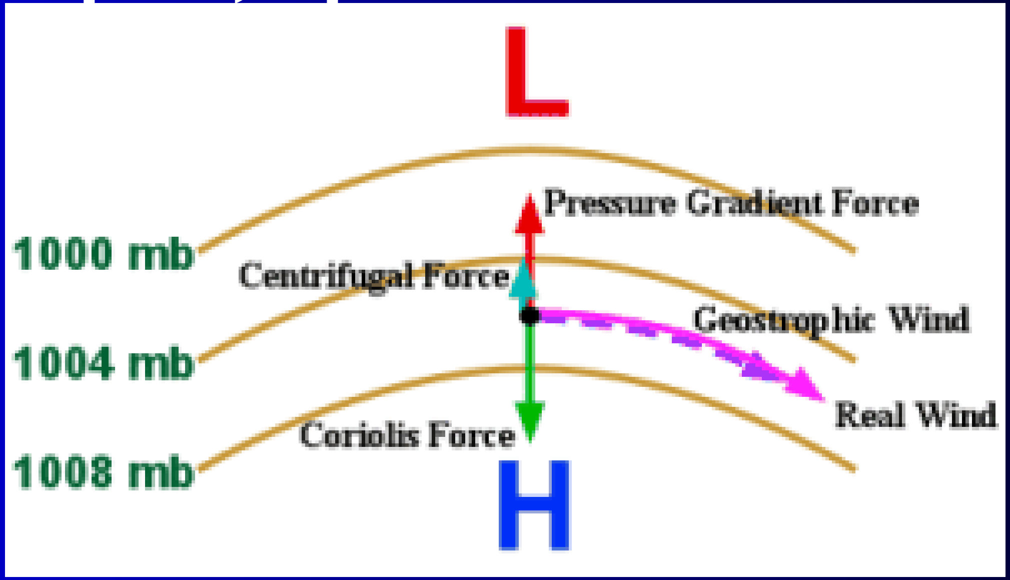
Since the pressure gradient force doesn't change, and all the forces must balance, the Coriolis force becomes weaker. This in turn decreases the overall wind speed. This is where the gradient wind differs from the geostrophic winds. **In this case of a low pressure system or trough, the gradient wind blows parallel to the isobars at a less than geostrophic (subgeostrophic) speed**.



This also applies to high-pressure systems as well. In this case, again starting from point A, the geostrophic wind will blow straight south. This time the centrifugal force is pushing in the same direction as the pressure gradient force, and when it gets slightly further away from the center, the centrifugal force again reduces, but this time that makes the Coriolis Force more dominant and the air parcel will move back to its original radius -- again d blowing parallel to the



Since the pressure gradient force still doesn't change, the Coriolis force must again adjust to balance the forces. However now it becomes stronger, which in turn increases the overall wind speed. **This means that in a high pressure system or ridge, the gradient wind blows parallel to the isobars faster than geostrophic (supergeostrophic) speed.**

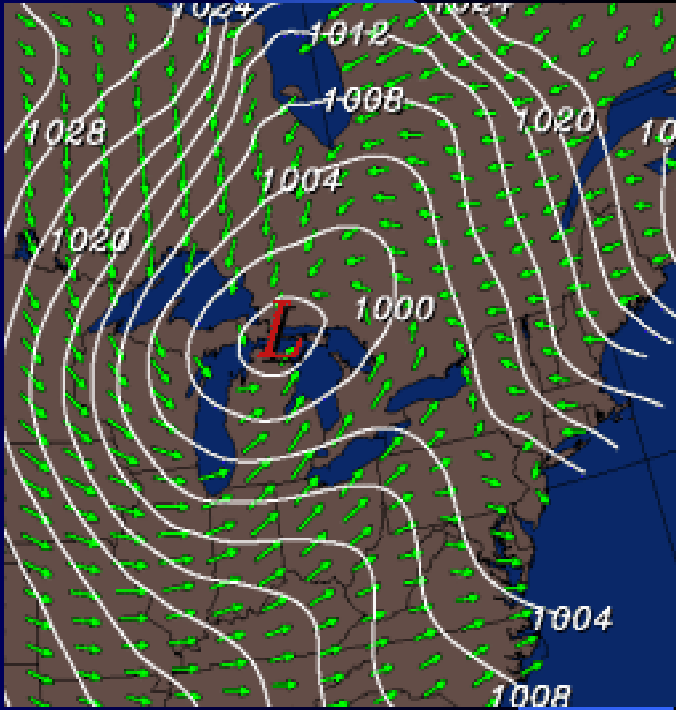


Winds near the surface

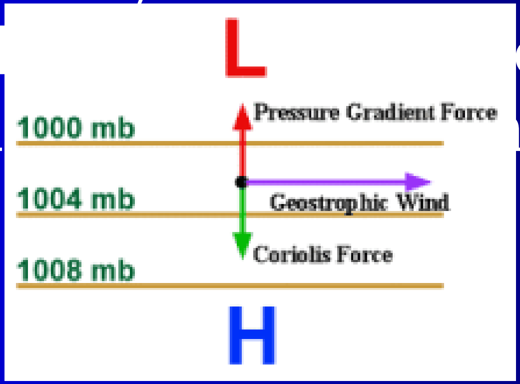
Winds affected by friction

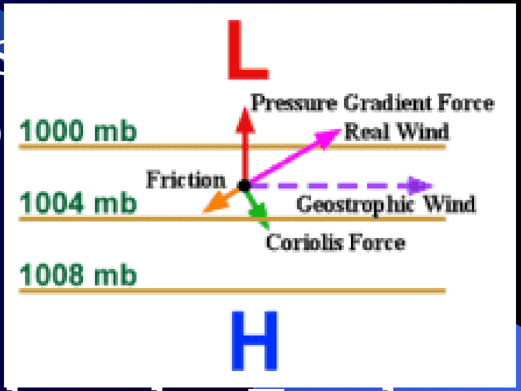
Geostrophic wind blows parallel to the isobars because the Coriolis force and pressure gradient force are in balance. However it should be realized that the actual wind is not always geostrophic -- especially near the surface.

The surface of the Earth exerts a frictional drag on the air blowing just above it. This friction can act to change the wind's direction and slow it down -- keeping it from blowing as fast as the wind aloft. Actually, the difference in terrain conditions directly affects how much friction is exerted. For example, a calm ocean surface is pretty smooth, so the wind blowing over it does not move up,



As we move higher, surface features affect the wind less until the wind is indeed geostrophic. This level is considered the top of the boundary (or friction) layer. The height of the boundary layer can vary depending on the type of terrain, wind, and vertical temperature profile. The time of day and season of the year also affect the height of th er. However, us boundary l n the surface to above it.



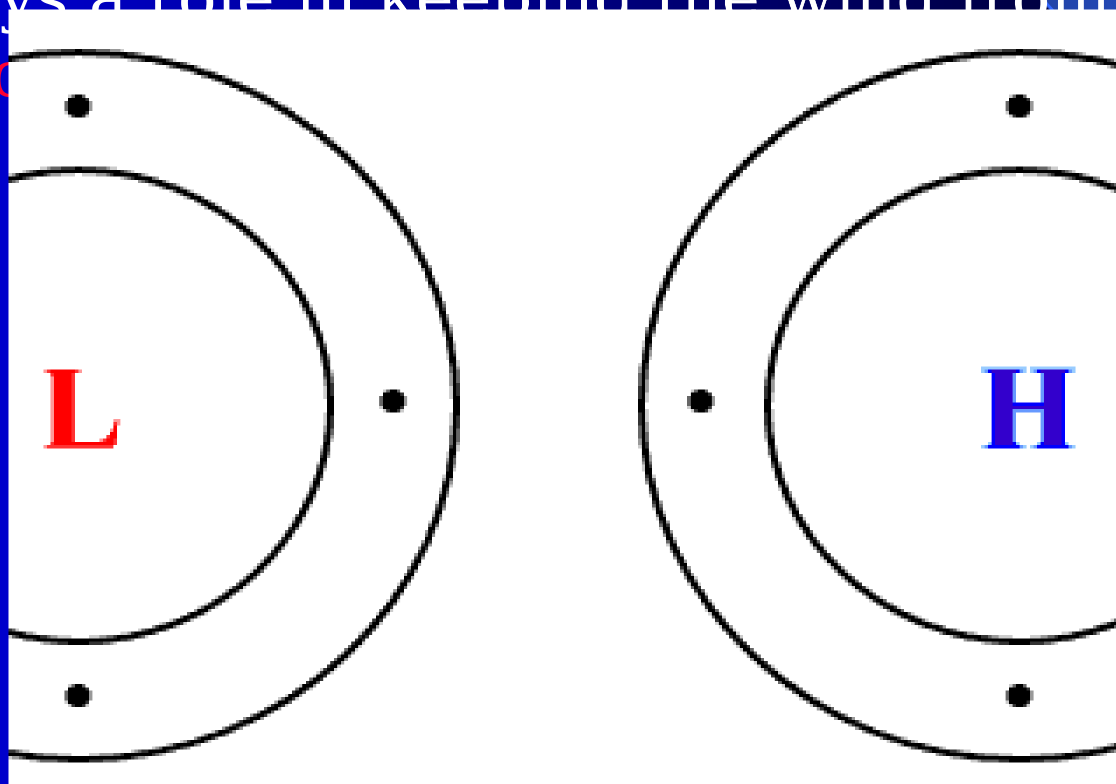


In the friction layer, the turbulent friction that the Earth exerts on the air slows the wind down. This slowing causes the wind to be not geostrophic. As we look at the diagram above, this slowing down reduces the Coriolis force, and the pressure gradient force becomes more dominant. As a result, the total wind deflects slightly towards lower pressure. The amount of deflection the surface wind has with respect to the geostrophic wind above depends on the

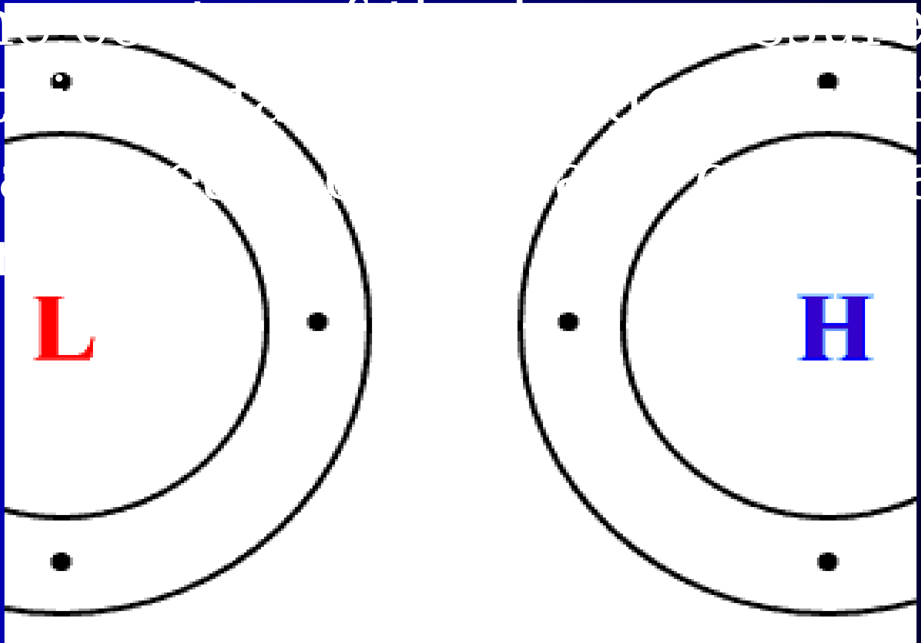
Boundary Layer Winds

more of friction's impact on low level winds

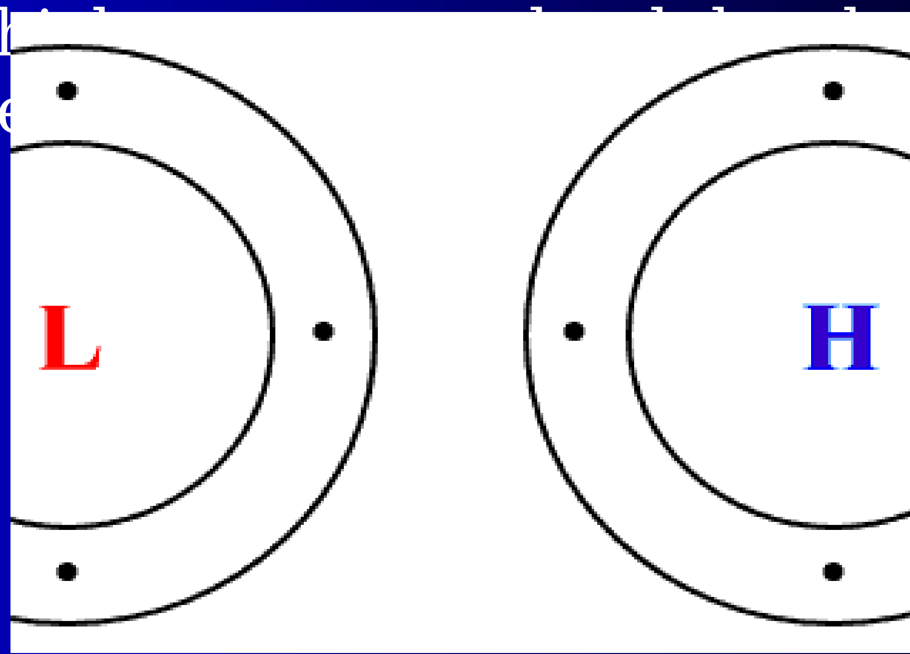
Friction's effects on air motion decrease as the altitude increases -- to a point (usually 1-2 km) where it has no effect at all. The depth of the atmosphere that friction does play a role in atmospheric motion is referred to as the boundary layer. Within the boundary layer, this friction plays a role in keeping the wind from being geostrophic



If we look at low and high-pressure systems, we can see this mechanism at work. Here in this exmple below, the winds would, without friction effects, be moving counter-clockwise around the center of the low in the northern hemisphere. However, when the surface friction is accounted for, the wind slows down, and therefore the Coriolis force weakens and the pressure gradient force becomes dominant, resulting in the spiraling of air into the center of a low pressure system and away from the center of the high pressure system. This causes convergence in th… e system at the surface. It is t… ich leads to rising air which ca… ause rain and storms to for…



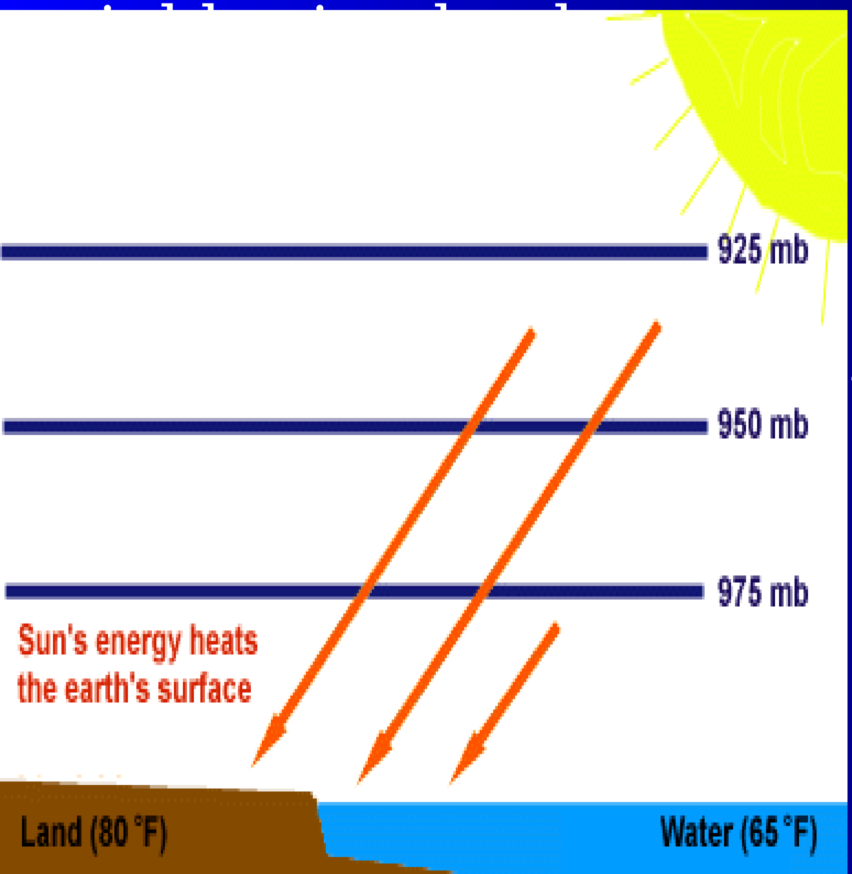
At the same time, wind flows around a northern hemisphere high-pressure system in a clockwise manner, but when frictional effects are introduced the wind again slows down, and the Coriolis force reduces and the pressure gradient force becomes dominant. In this case, though, the pressure gradient is outward from the center of the high, so the result is that surface wind spirals away from the center. This causes divergence (convergence) in the center of the high (low) pressure system at the surface. This surface divergence causes sinking motion wh ment and gives us clear skie



Sea Breezes

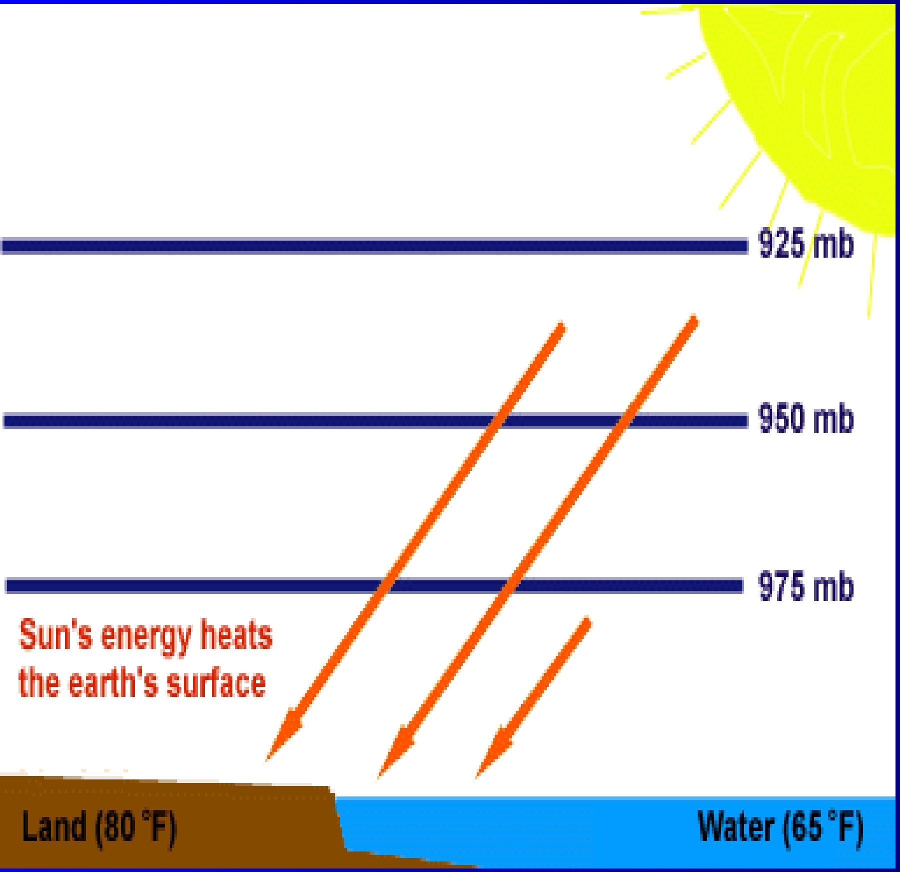
a result of uneven surface heating

When spending a day at the beach, a noticeable drop in temperature may occur during the early afternoon as a cool breeze begins to blow off of the water. This wind is known as the "sea breeze", which occurs in response to differences in temperature

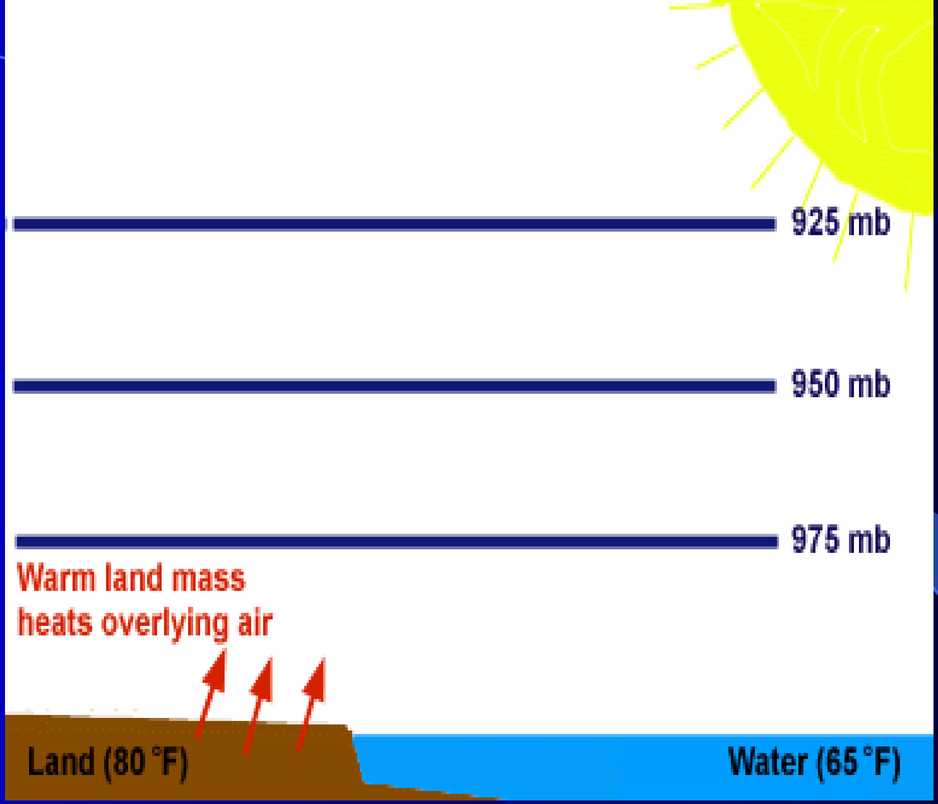


Sea-breeze circulations most often occur on warm sunny days during the spring and summer when the temperature of the land is normally higher than the temperature of the water. During the early morning hours, the land and the water start out at roughly the same temperature. On a calm morning, a given

A few hours later, the sun's energy begins to warm the land more rapidly than the water. By later in the day, the temperature of the land increases while the temperature of the water remains relatively constant. This occurs because water, especially large bodies of water like a lake or ocean, are able to absorb more energy than land



It is important to remember that the air is not heated directly from above by the sun. In fact, most of the incoming solar energy actually passes right through the atmosphere. However, as the land absorbs this energy, heat is radiated back into the atmosphere (from the earth), warming the overlying air.

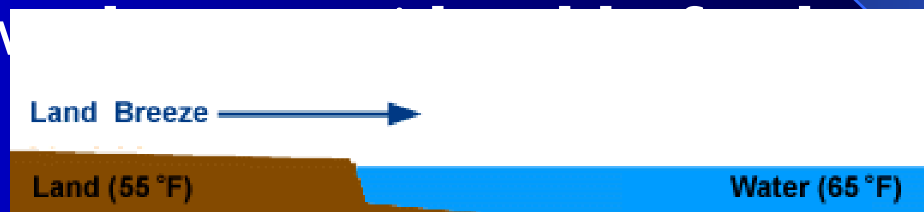


On the other hand, since the temperature of the water remains relatively constant throughout the day, the air over the water is not heated from below (as over land), resulting in lower air temperatures over the water.

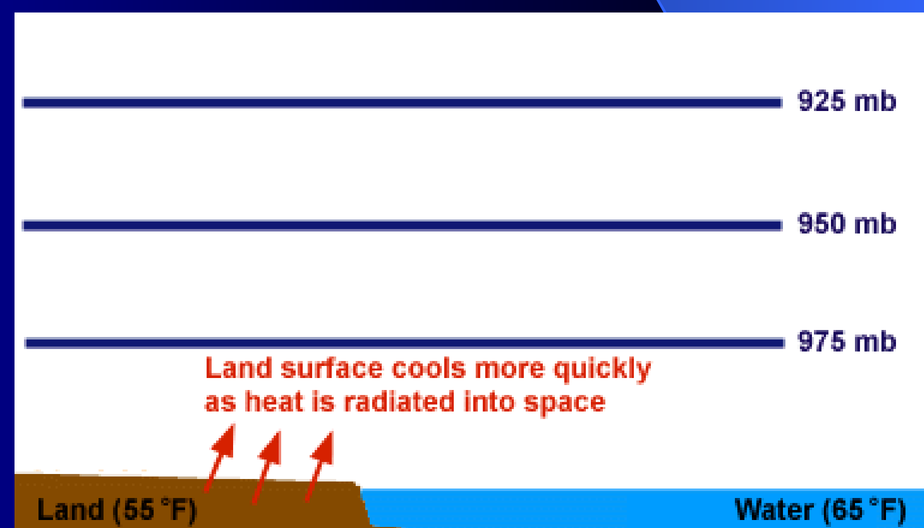
Land Breezes

begin with the cooling of low-level air

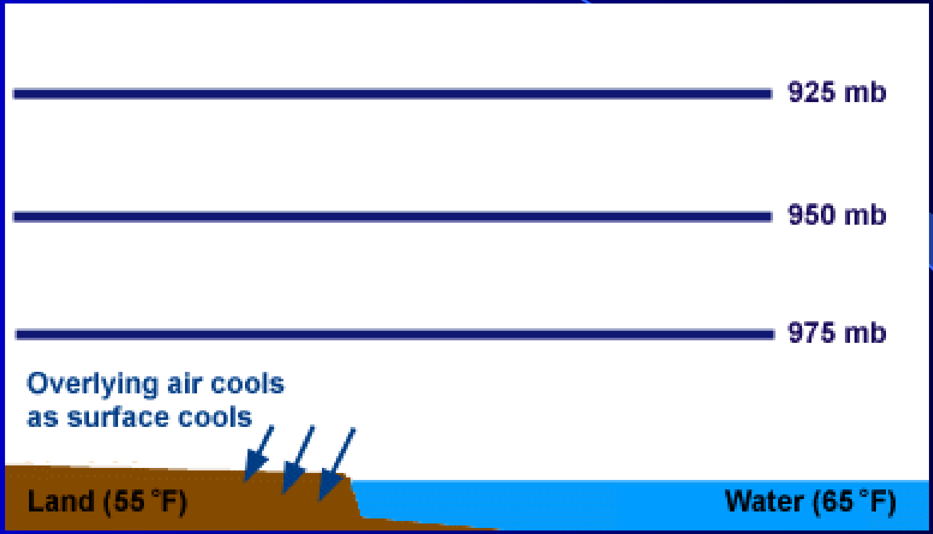
On clear, calm evenings, temperature differences between a body of water and neighboring land produce a cool wind that blows offshore. This wind is called a "land breeze". Land breezes are strongest along the immediate coastline but w … inland.



Land-breeze circulations can occur at any time of year, but are most common during the fall and winter seasons when water temperatures are still fairly warm and nights are cool.

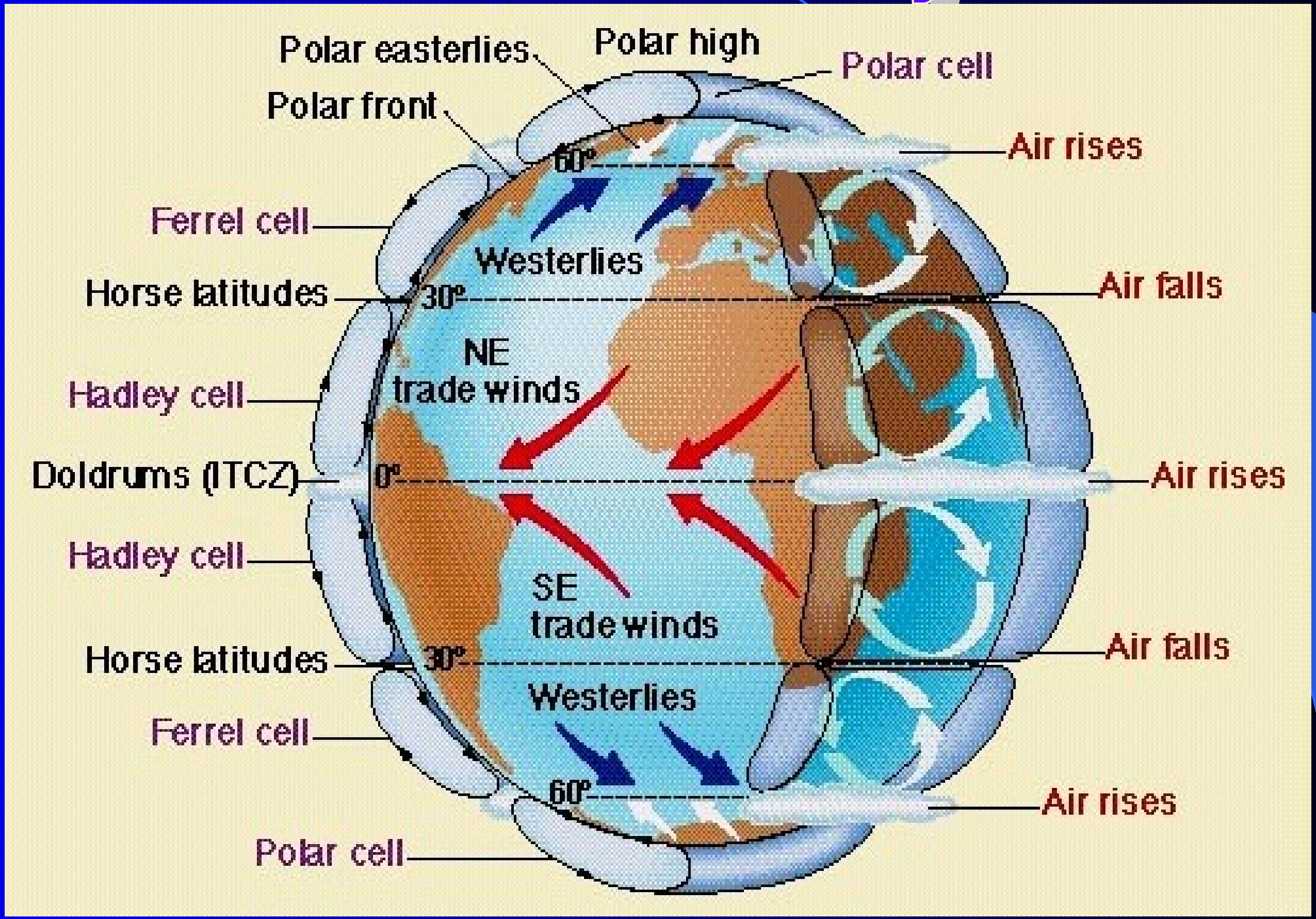


On clear and calm evenings, the earth's surface cools by radiating (giving off) heat back into space, and this results in a cooling of the immediately overlying air.



Since the air over land cools more rapidly than the air over water, a temperature difference is established, with cooler air present over land and relatively warmer air located over water.

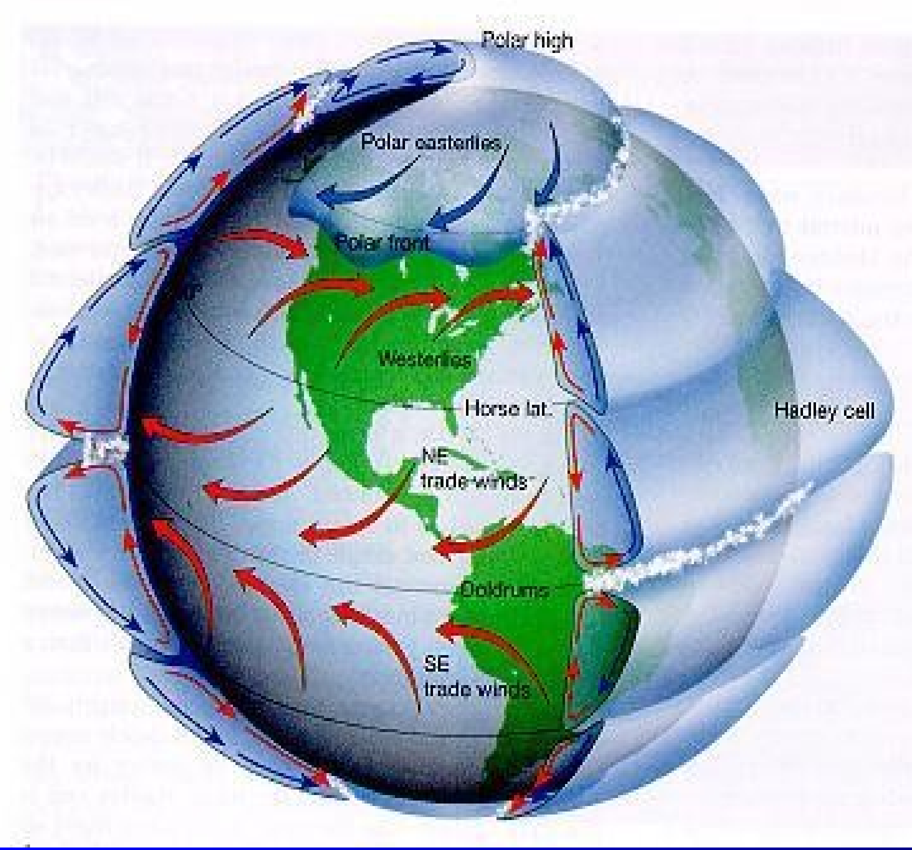
Global Wind Systems



Atmospheric Circulation

Global circulation on a non-rotating Earth. A simple convection system is produced by unequal heating of the atmosphere on a non-rotating Earth.

Sir Hadley was the first scientist to suggest that the winds on the Earth would be created by the differential heating of the atmosphere between the equator and the poles. He proposed a convective model much like the one



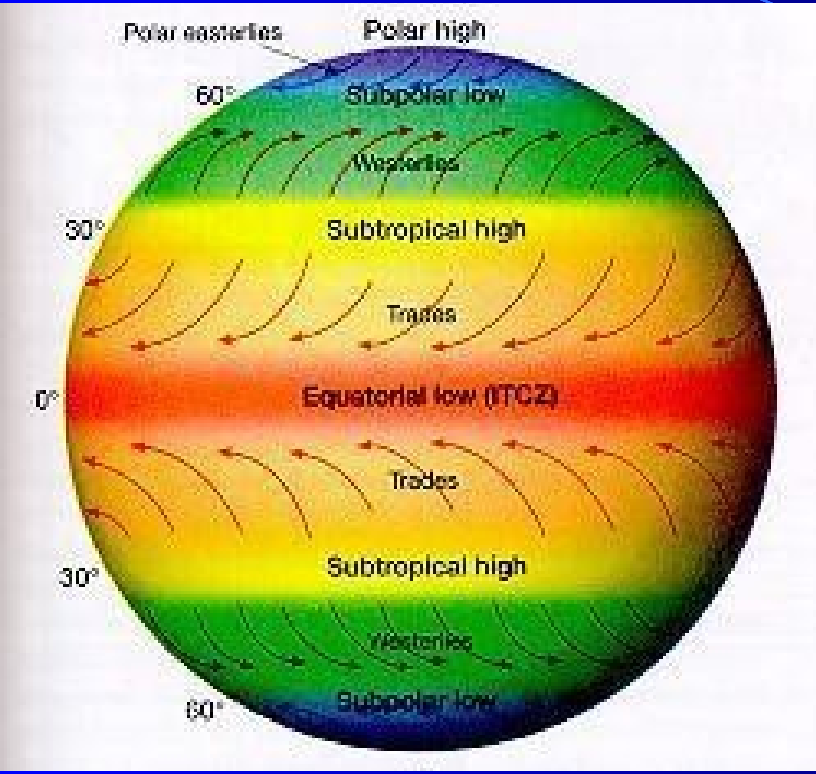
The cooling of the air as it moves from the equator towards the poles causes the distinct convective cells

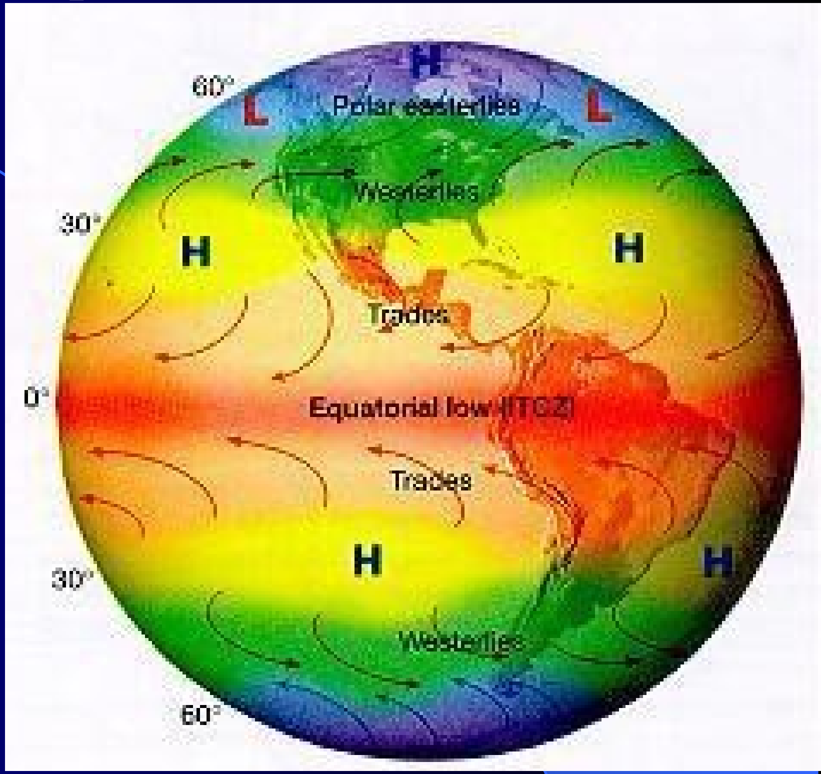
The Earth's rotation creates the circular motions of these convective cells.

Although Hadley was not quite right in his conceptual model of air convection his idea does largely apply to the individual cell closest to the equator. In his honor this convective cell has been name the Hadley Cell.

Divergence and Convergence

Idealized Earth with only zonal pressure belts

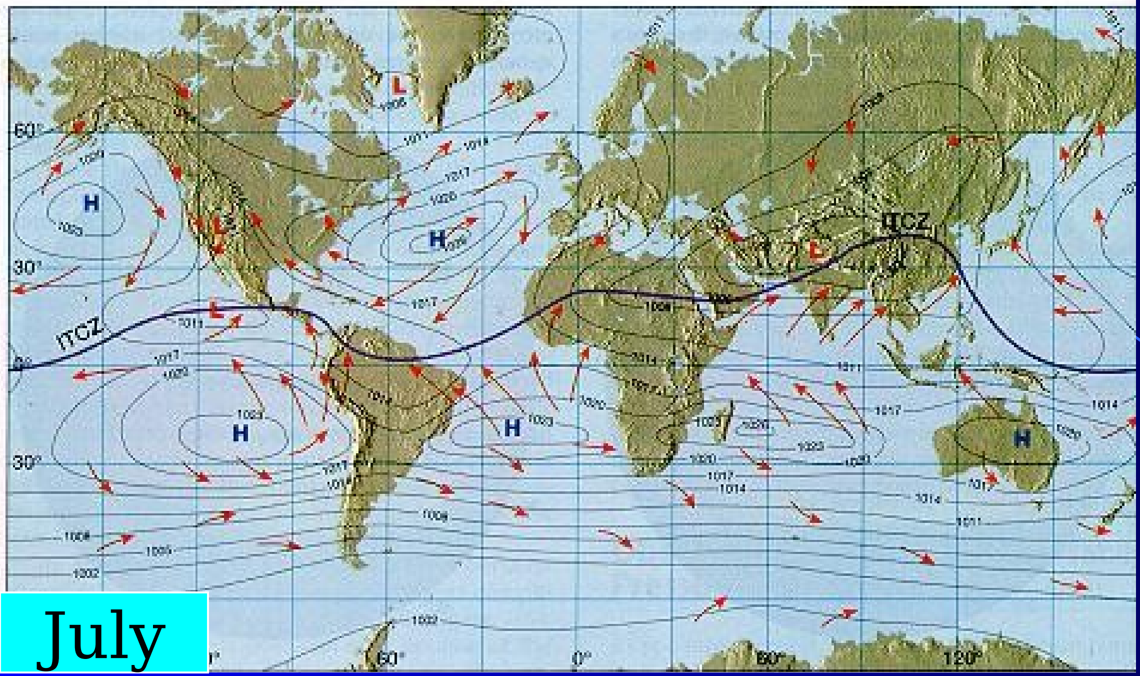




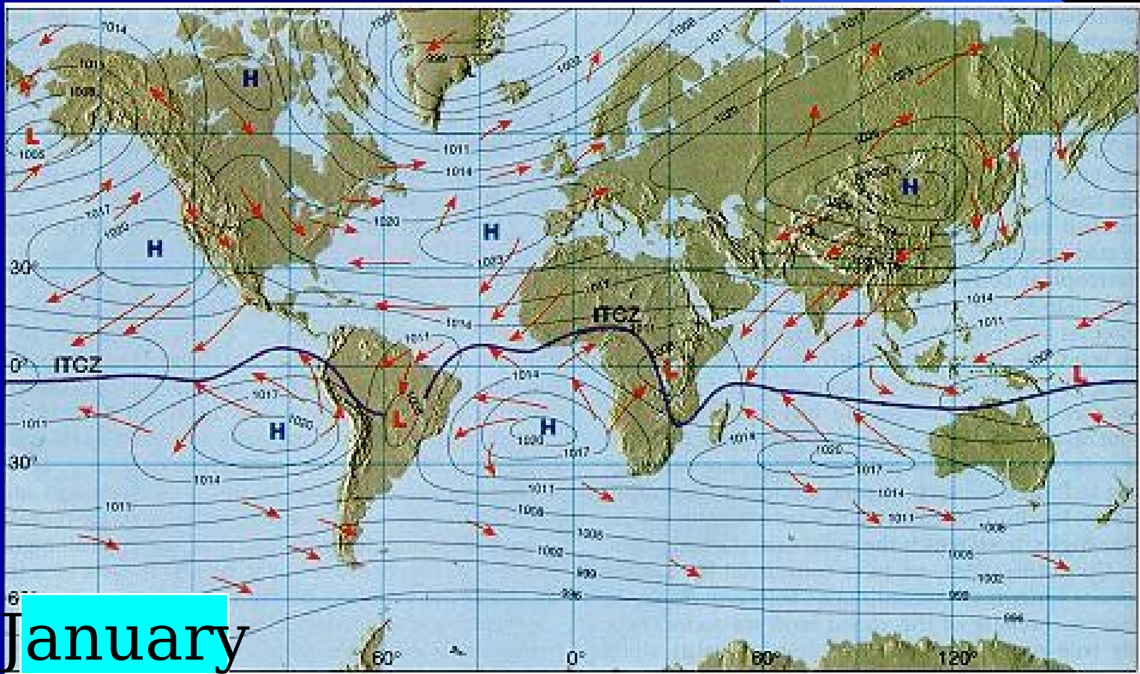
An imaginary uniform Earth with idealized zonal (continuous) pressure belts.

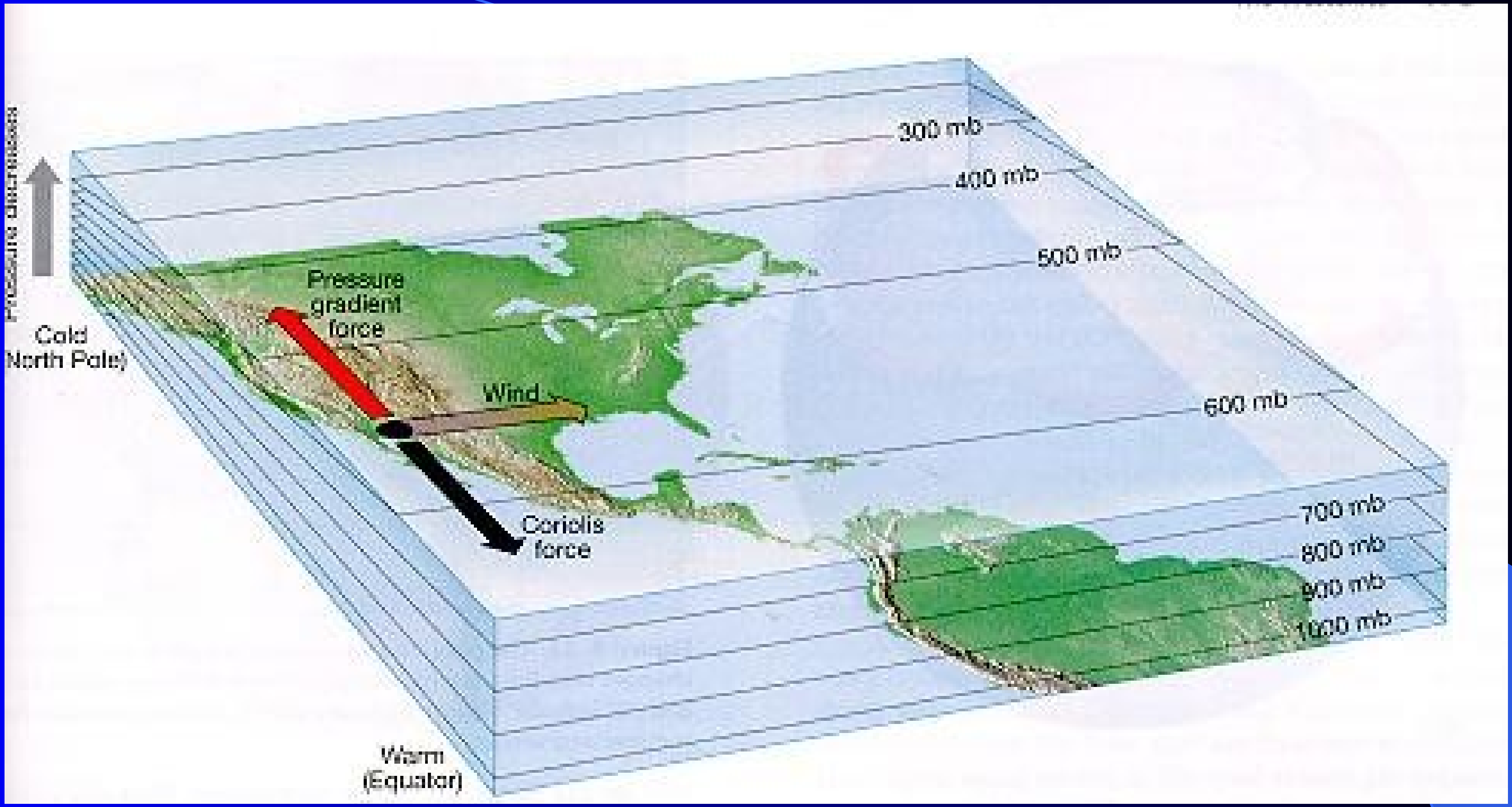
The real Earth with disruptions of the zonal pattern caused by large landmasses. These disruptions break-up pressure zones into semi-permanent high- and low-pressure cells.

Differential heating in the northern and southern hemisphere creates movements in the general location of the large circulation cells



The intertropical convergence zone (ITCZ) refers to the location near the equator where the winds from the southern and northern hemisphere converge

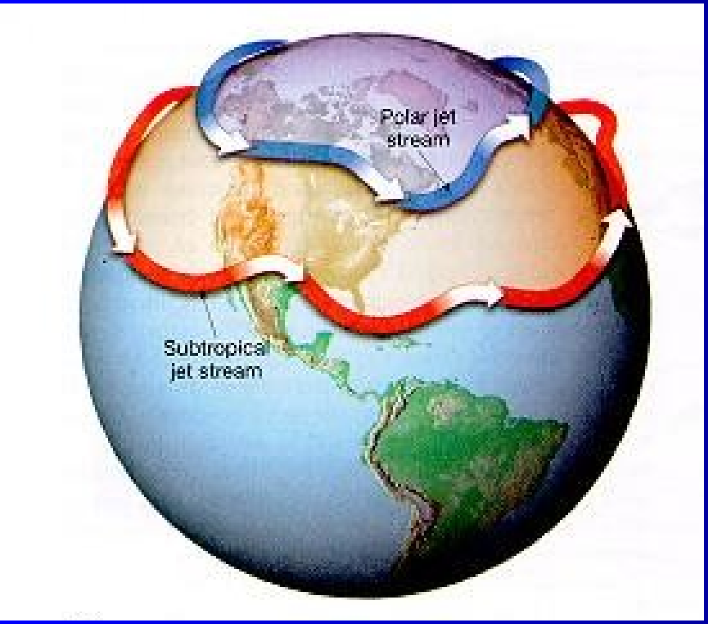




Idealized pressure gradient that develops aloft because of density differences between cold polar air and warm air.

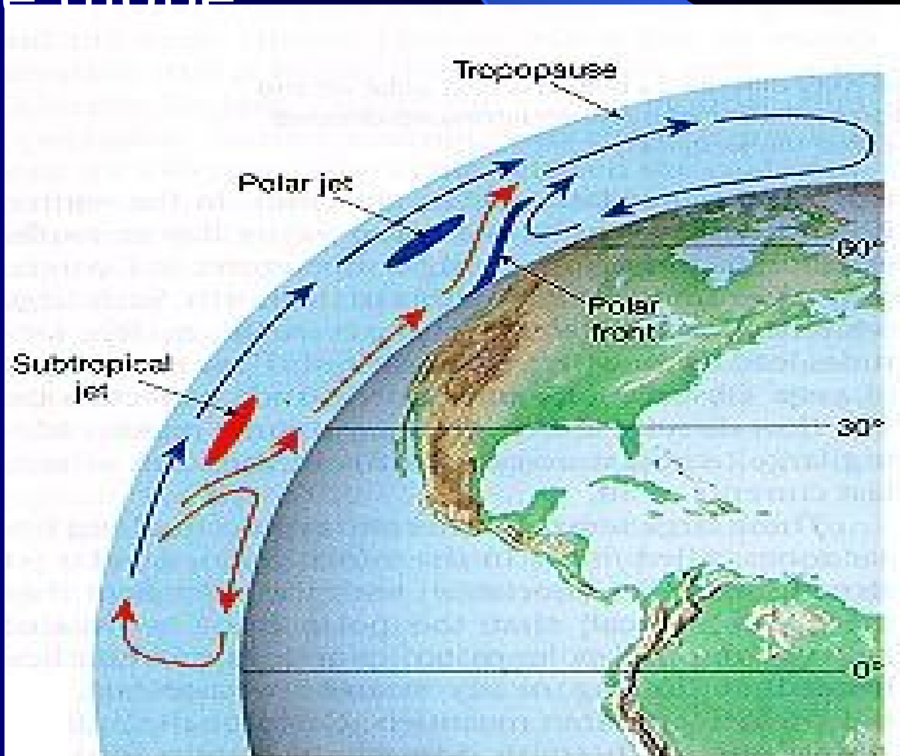
Jet Streams

The Jet Streams are ribbons of air moving within the geostrophic winds we call the Westerlies.

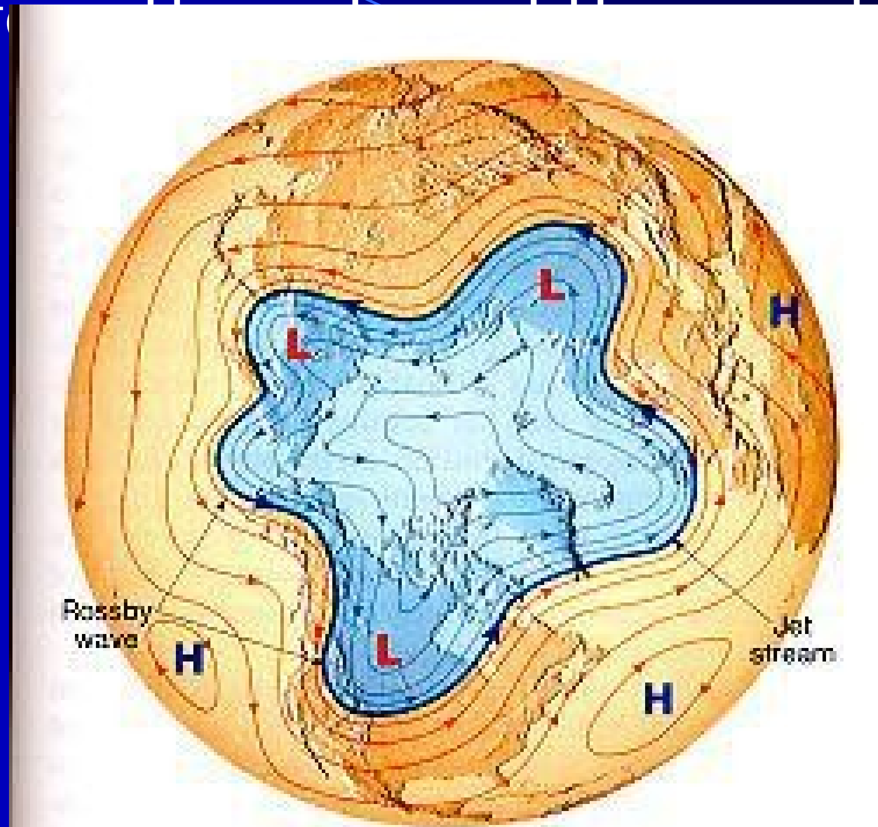


Approximate position of the polar and subtropical jet streams. Note that these fast-moving currents are generally not continuous around the entire globe.

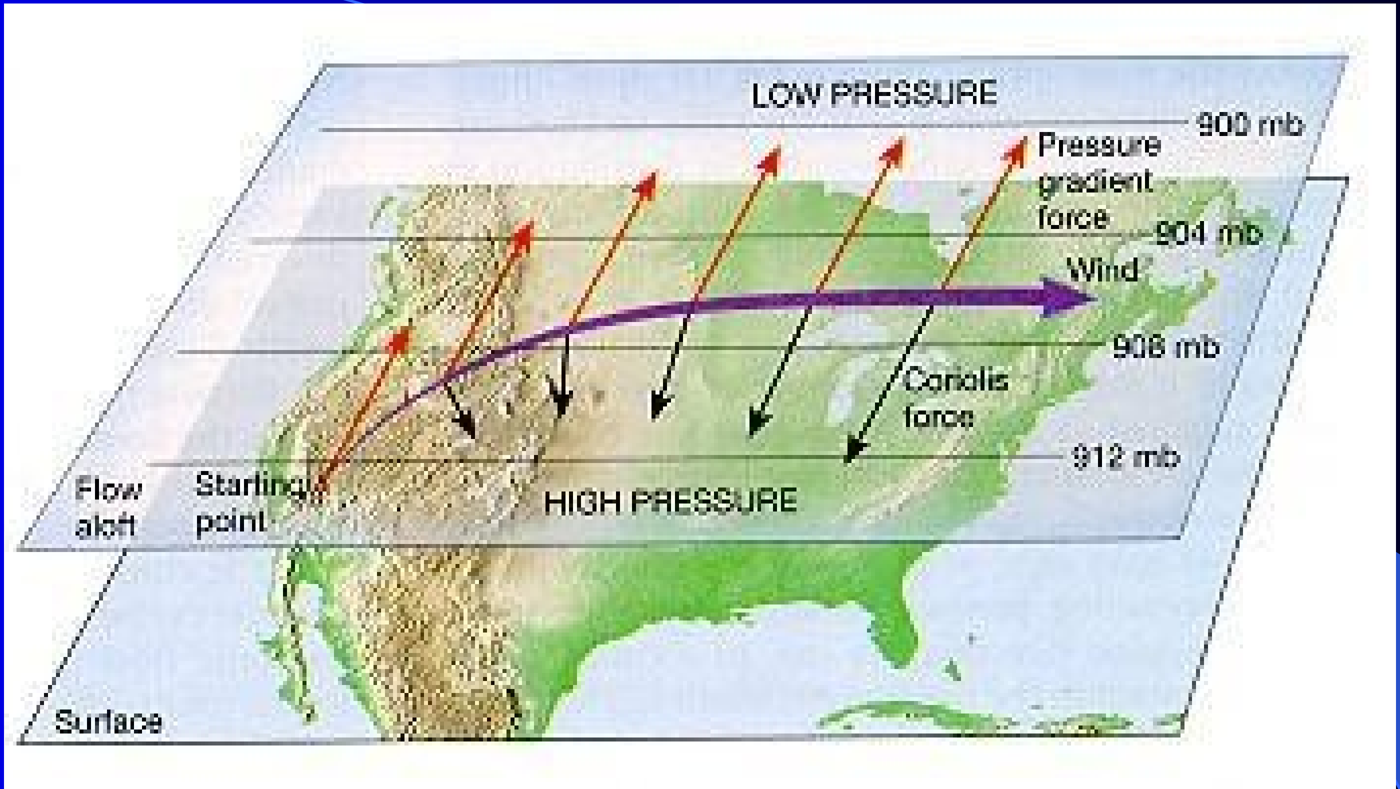
A cross-sectional view of the polar and subtropical jets.



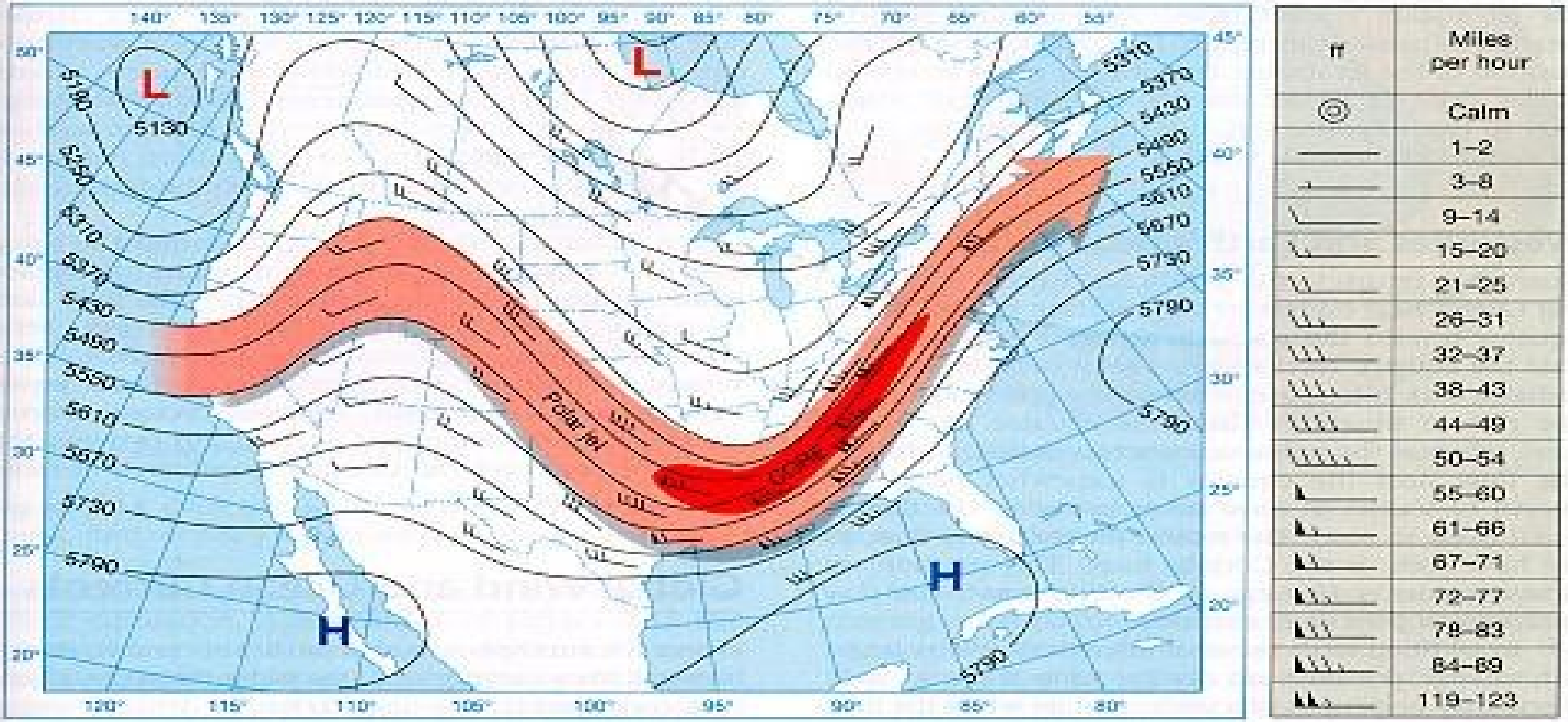
The position of the of the jet stream varies with the season. This is because of the changes in the thermal gradients betw or.



Idealized air flow of the westerlies at the 500 Mb level. The 5 long-wavelength undulations, called Rossby waves, compose this flow. The jet stream is the fast core of this wavy flow

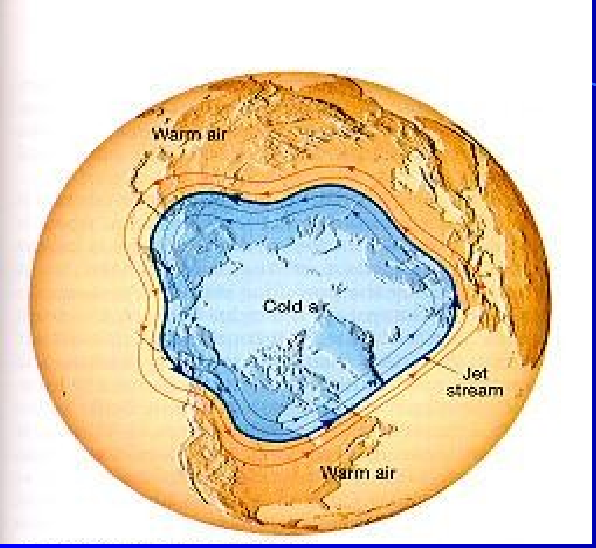


If the Earth did not rotate, upper level winds would flow directly from area of higher pressure to areas of lower pressure. However, upper level winds are deflected by the Coriolis force and the pressure gradient force. Above 600 meters, where friction is negligible, winds flow nearly parallel to the isobars and are called geostrophic

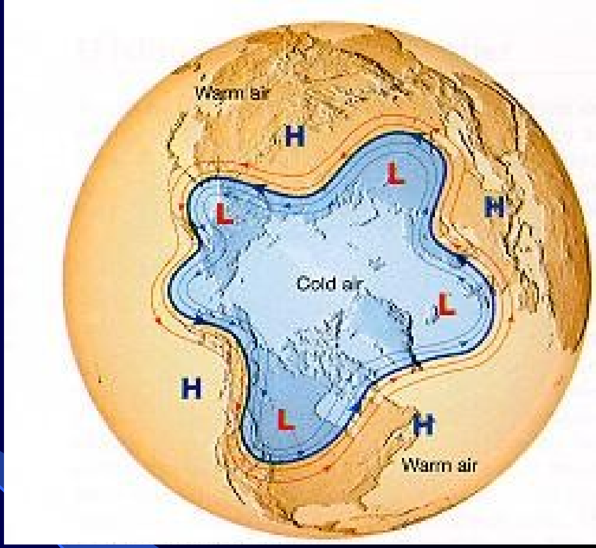


Simplified 500 Mb height contour chart for January. The position of the jet stream core is shown in dark red.

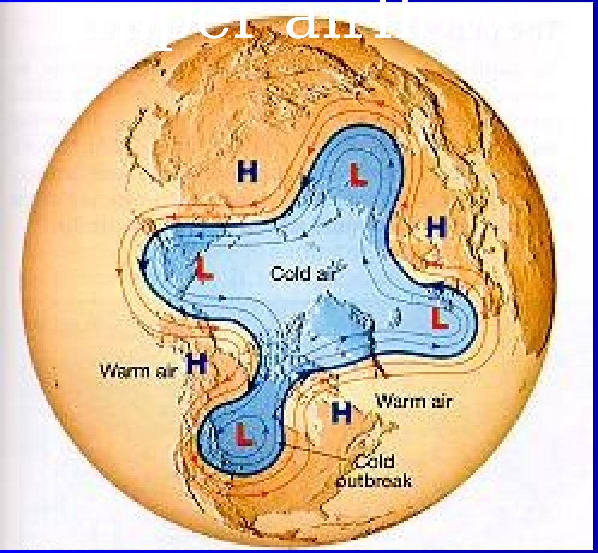
Representation of upper-level chart



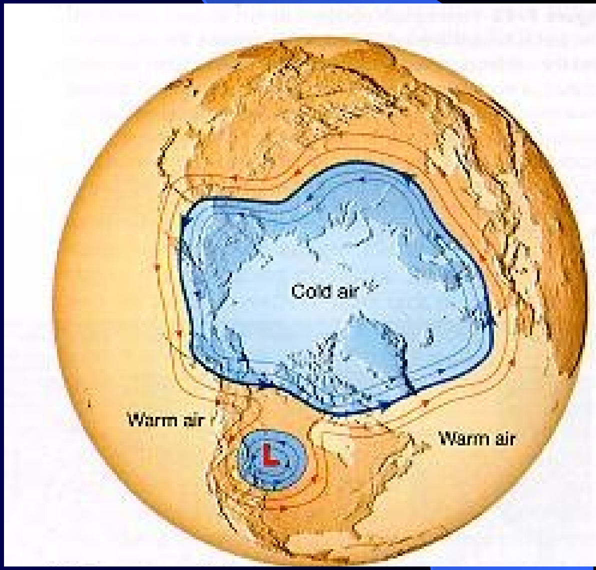
Gently undulating



Meanders form in jet stream.



Strong waves form in upper



Return to a period of flatter